Historic, archived document

Do not assume content reflects current
scientific knowledge, policies, or practices.

UNITED STATES DEPARTMENT OF AGRICULTURE

DEPARTMENT BULLETIN No. 1430

Washington, D. C. ▼ August, 1926

LIBRARY
U. S. D. A.
BUREAU OF
HOME ECONOMICS

FINANCIAL LIMITATION IN THE EMPLOYMENT OF FOREST COVER IN PROTECTING RESERVOIRS

By

W. W. ASHE, Assistant District Forester
Forest Service

CONTENTS

Page
Possibilities in the Storage of Storm Water for Power 1
Necessity of Permanency of Power Reservoirs 2
Influence of Forest Protection on Silting 3
Sources of Solid Burden of Streams 5
Relative Value of Forest and Other Cover in Reducing Erosion of Soil 9
Cost and Value of Reduction in Erosion Through Forest Planting 10
Settling Basins 15
Planting a Wood 16
Regimen and Turbidity of the Main Stream Systems in the United States 17
Summary 32

WASHINGTON
GOVERNMENT PRINTING OFFICE
1926

M. O. Leighton, of the United States Geological Survey, that with a minimum of 36,000,000 horsepower without storage there might with storage "eventually be established a total power installation of at least 200,000,000 horsepower and probably much more."

The minimum water-power resource of the eight southern Appalachian States, without storage, is placed by the United States Geological Survey at 3,340,000 horsepower. If storage of storm water is employed, this minimum can be increased, at a conservative estimate, to 5,678,000 horsepower. This increase is based upon the figures of the Geological Survey of Tennessee[2] indicating the possible increase in that State. Plans which have been worked out for the development of water power in Tennessee show that the power could be increased by storage 70 per cent above the minimum dry-season flow. Since the Tennessee River, on which these figures are based, is a large stream, its tributaries having their sources in six other States, it can reasonably be assumed that the water-power resources of the Appalachian and Piedmont regions as a whole might be increased in the same proportion.

A vast power plan which has been outlined by Harold C. Fiske for the full development of the Tennessee River calls for the construction of about 100 dams on the river above Knoxville. It is estimated that under this development there might be produced about 4,000,000 horsepower on the river at and above Muscle Shoals. The economic feasibility of this plan would depend largely upon the possibility of procuring at low prices much of the land which would be submerged by the reservoirs, many of which would be vast lakes.

This proposed plan may never be entirely consummated. In any event, if the enormous resource of this river at and above Muscle Shoals is to be adequately developed, it must be through a series of storage reservoirs, the ultimate value of which will depend upon the maintenance of storage capacity through reducing siltage.

NECESSITY OF PERMANENCY OF POWER RESERVOIRS

The value of a storage reservoir depends largely upon its life, that is, upon the permanency of its storage capacity. The rate at which erosion of soil is taking place on the basin of the supplying stream is the all-important factor in determining the period of service, or the number of years which will elapse before the soil removed by heavy rains from the lands on its catchment areas will fill the reservoir.[3] (Pl. 2, figs. 1 and 2.)

Many engineers, accepting siltage in certain regions as a natural condition, customarily determine the life of a reservoir and ascertain whether the earnings will provide for the amortization of its costs. There are regions, as will be pointed out, where methods for the control or reduction in silting are impossible or impracticable.

---

[2] SWITZER, J. A. THE WATER POWERS OF TENNESSEE. Tenn. State Geol. Survey Bull. 17, 137 pp., illus., 1914.

[3] In most cases it is not possible to remove economically the silt deposited above the dam. To do so would often mean merely passing it to a reservoir lower down on the stream. It is suggested that the proposed Boulder Canyon Reservoir on the Colorado River be flushed, after draining it, once in about 10 years by means of a reservoir located above it and employed only for this purpose. It is doubtful, however, if this can actually be done since the river at present carries its full load of silt and the load could not be materially increased by flushing. There are likewise mechanical difficulties. But if such a system could ever be employed it might also be used most advantageously on the streams of middle and western Texas with their high silt burden.

The loss in investment, however, through the silting up of a storage reservoir on a head stream is trivial when compared with the actual loss to the region of the reservoir site; for when the storage capacity of a reservoir has once been destroyed the site can not be replaced. For this reason, it is of paramount importance that, wherever it is possible, the permanence of the reservoir be assured through adequate protection of the stream basins.

Just as the public is demanding that hydroelectric developments shall not be made piecemeal, but that they shall be so coordinated as to obtain the full and complete use of power possibilities, so it will require that the catchment area shall be protected from erosion as thoroughly as the physical conditions justify. This restriction would not apply to dams constructed largely to secure fall and not to provide storage, but only to such reservoirs as are located at or near headwaters and designed to provide storage, which will modify the regimen of the river, affecting its power possibilities and possibly its use for navigation, and tending to lessen floods.

It is believed that the same public conscience which now demands that the earning value of forest lands shall not be destroyed will also soon require the protection of reservoir basins, in the same manner perhaps as sanitation is now often provided for. Hydroelectric engineers and investors in water-power securities, as well as industries using hydroelectric power, should all be vitally interested in obtaining such protection to basins employed for water storage.

INFLUENCE OF FOREST PROTECTION ON SILTING

Excessive erosion in the forested parts of the United States is largely the result of unnatural conditions, and on many head streams it can be prevented or greatly reduced. Notwithstanding the fact that there are many reservoirs which have become so silted up that only the channel of the stream remains, this is not the natural condition for most streams the sources of which are within well-wooded regions; it is a condition produced very largely and often entirely through exposure of the naked soil—the removal of the protective cover of forest and of forest litter and humus. (Pl. 3, figs. 1 and 2.)

Though a number of reservoirs have silted flush except for the stream channel, these are chiefly on the smaller streams or where the solid burden contains a large proportion of coarse material. The reservoirs on larger streams where most of the material being transported consists of finer silt more easily held in suspension do not seem in all cases to silt flush, or they do so very slowly. There is a relatively rapid silting on the upper portions of the reservoirs. The silting then proceeds less rapidly until a stage is reached at which the rate of silting is materially reduced, either because eddies and convective currents hold matter in suspension or because velocity during floods scours the silt above a certain level. There are local features in nearly every reservoir which control the rate and the ultimate extent of deposit.

A matter for serious consideration also is the control which should be exercised by the States in preventing an increase in the solid burdens of streams in cases where such an increase would jeopard valuable power sites. In certain States large sums of money are spent by the Federal Government for channel dredging or for the purchase of woodland for the protection of stream flow, yet many States have taken no measures to check or control stream pollution. Enormous quantities of earth from mines, from washing kaolin, or from other sources are deposited in streams without protest. Thousands of acres of land too steep for permanent profitable cultivation are cleared, only to be abandoned, the subsequent erosion adding to the streams tons of silt, much of which is deposited, destroying reservoir space and increasing the cost of power or filling navigable channels. Later these deposits are removed at the expense of the general public, when a careful exercise by the State of its police power would have maintained the land in some form of permanent productivity, would have avoided much of the wasted effort in clearing it, and would have prevented the needless expenditure of public funds in the removal of silt beds from stream channels.

The western streams from Colorado and middle California northward which have their sources in the forested mountains are largely clear, or of prevailingly low turpidity, until they enter the treeless plains. Those which have their sources in and flow through the wooded regions of the Northeast are likewise clear. The headwaters of the Appalachian and southeastern Piedmont Rivers are clear and carry little silt burden so long as their watersheds are protected from erosion. Tallulah River in northeastern Georgia, on which are located two large storage reservoirs, is a typical stream of this kind. One of these reservoirs was recently emptied after 10 years of service, and when it was examined only a trace of sedimentation was found. There are, however, a few small clearings on the catchment area of this river. If such of these clearings as are hilly or have a rolling surface had not been cultivated, it is probable that even this trace of sedimentation would have been less. The North Fork of Swananoa River, from which the city of Asheville, N. C., obtains its supply of domestic water, has a very broken surface but is entirely forested. During very prolonged and heavy rains there is considerable turpidity, chiefly from leaching of vegetable matter, which is eliminated in a settling basin; at other times there is none. This small river is one of the head streams of the Tennessee River. The influence of the forest on soils subject to erosion is indicated by the difference between such head streams with forested basins and the Tennessee River in its lower reaches where it draws from similar soils unprotected by forest cover. So great is the silt burden of the main Tennessee River[4] that the pool above the dam at Hales Bar is reported[5] by the engineer in charge to have silted up in many places to the surface of the water, only the channel for the flow of the river remaining open.

Whether forests exercise any beneficial influence upon stream flow is beyond the scope of this bulletin. Certain hydrographers claim that they do not.[6] If the advocates of the protective values of for-

---

[4] From data furnished by Herman Stabler, of the U. S. Geological Survey, it is computed that the Tennessee River, with a basin of 35,000 square miles, yearly transports nearly 11,000,000 tons of earth.

[5] MATTHES, GERARD H. TENNESSEE RIVER AND TRIBUTARIES, NORTH CAROLINA, TENNESSEE, ALABAMA, AND KENTUCKY. APPENDIX A. U. S. Congress, 67th, 2d sess., House Doc. 319, p. 110. 1922.

[6] It is the opinion of D. W. Mead that forests exert practically no influence upon stream flow in Wisconsin, and F. E. Frothingham has recently made the same statement regarding forest cover in relation to the streams of New England. FROTHINHAM, F. E. FORESTRY, HYDRO-ELECTRIC DEVELOPMENT, AND CONSERVATION. N. Y. Forestry, 9 : 18–19. 1923. But Charles L. Potter, president, Mississippi River Commission, is inclined to the view,

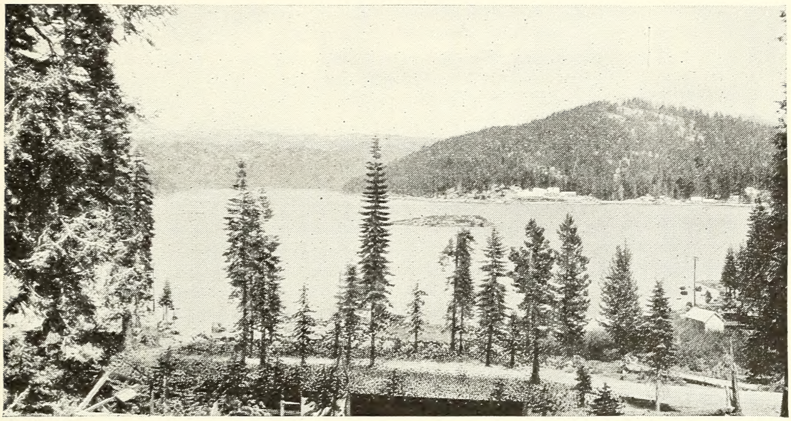


PHOTO BY F. E. BONNER

A REGION WHERE FORESTS HAVE HIGH PROTECTIVE VALUE

FIG. 1.—Huntington Lake, southern Sierras of California. Along the lower Sierras long periods without rain are broken by a short rainy season often marked by most concentrated precipitation. As a result ground cover is often thin or lacking. At Springville 42 inches of rain has fallen within a month. In seven consecutive months of the same year less than 2 inches fell. Similar concentrated precipitation is recorded at Summerdale, North Fork, Milo, Huntington Lake, Hot Springs, and other places in the southern Sierras

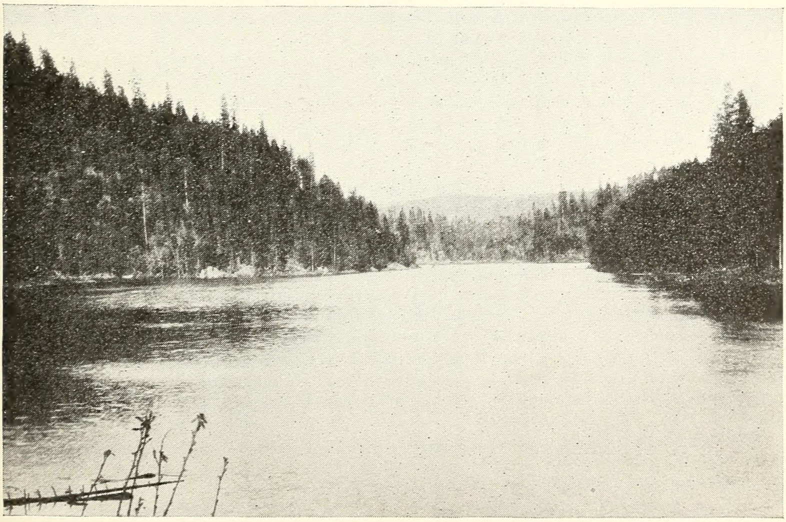


PHOTO BY FEDERAL POWER COMMISSION

HIGH VALUE OF FOREST COVER

FIG. 2.—Reservoir in Yuba County, Calif., on North Fork of Yuba River. A region of prevailingly low but often concentrated and irregular precipitation, and subject to destructive erosion of naked soil

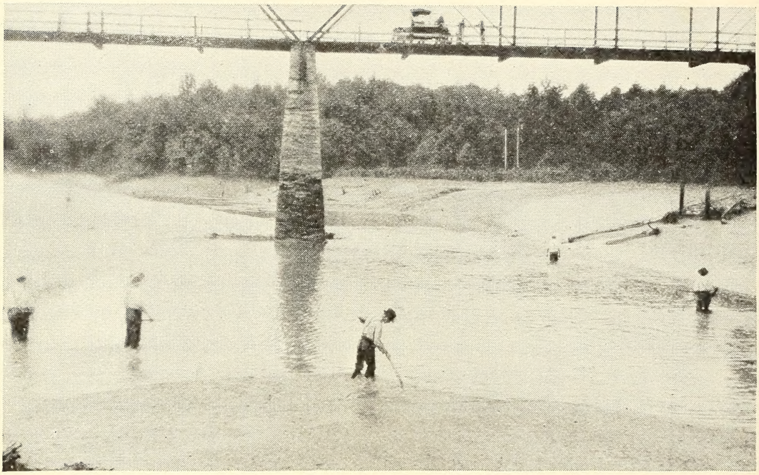


PHOTO BY THORNDYKE SAVILLE, N. C. GEOLOGICAL AND ECONOMIC SURVEY

REMOVING SILT FROM RESERVOIR

FIG. 1.—Reservoir on Deep River, N. C. Pondage so reduced by siltage that twice a year it is necessary to draw down the water to allow the silt to be removed in front of the wheel inlets

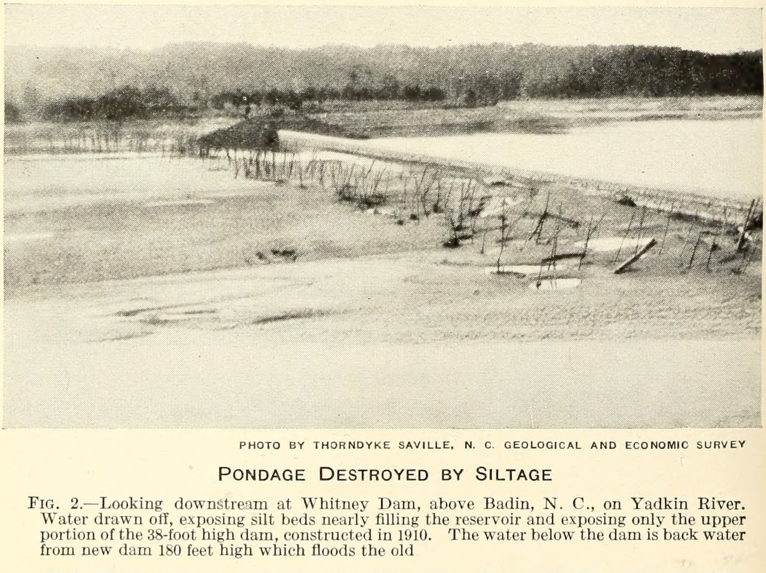


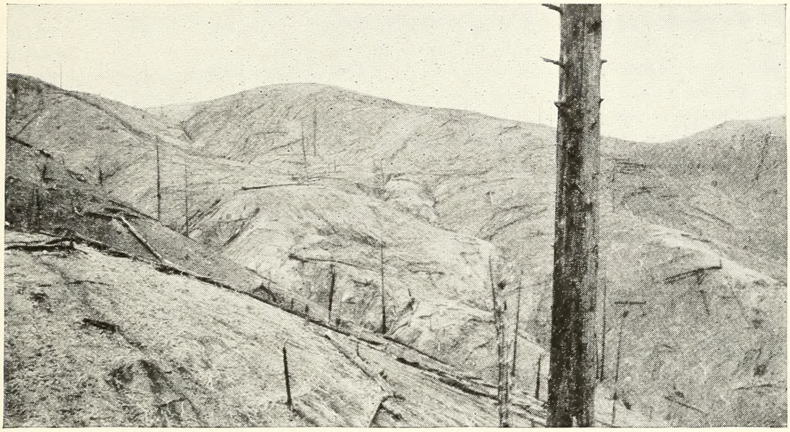
PHOTO BY THORNDYKE SAVILLE, N. C. GEOLOGICAL AND ECONOMIC SURVEY

PONDAGE DESTROYED BY SILTAGE

FIG. 2.—Looking downstream at Whitney Dam, above Badin, N. C., on Yadkin River. Water drawn off, exposing silt beds nearly filling the reservoir and exposing only the upper portion of the 38-foot high dam, constructed in 1910. The water below the dam is back water from new dam 180 feet high which floods the old

HOW EROSION OF SOIL INCREASES THE COST OF POWER

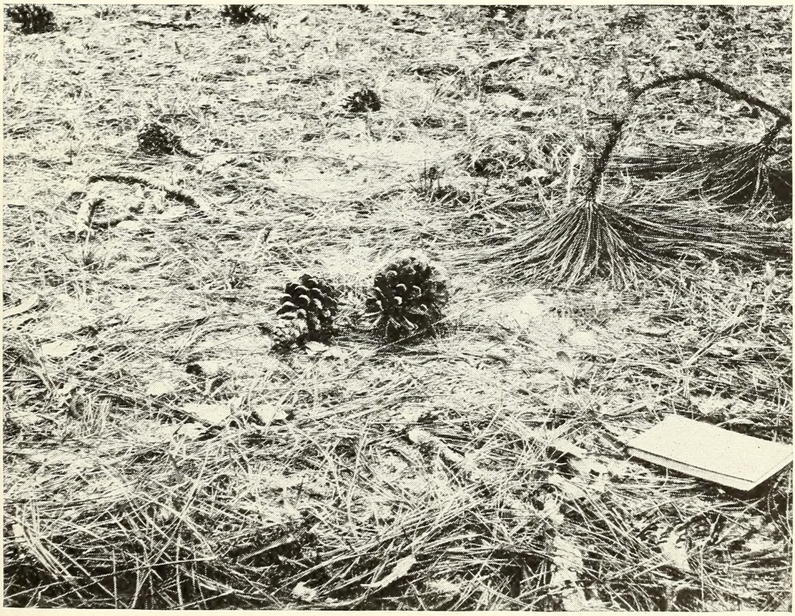
A reservoir which lasts only 25 years must be paid for within that time by the users of its power



F175366

EROSION OF EARTH FOLLOWING DESTRUCTION OF VEGETATION

FIG. 1.—Forests destroyed by smelter fumes. The soil is unprotected and erosion is most destructive

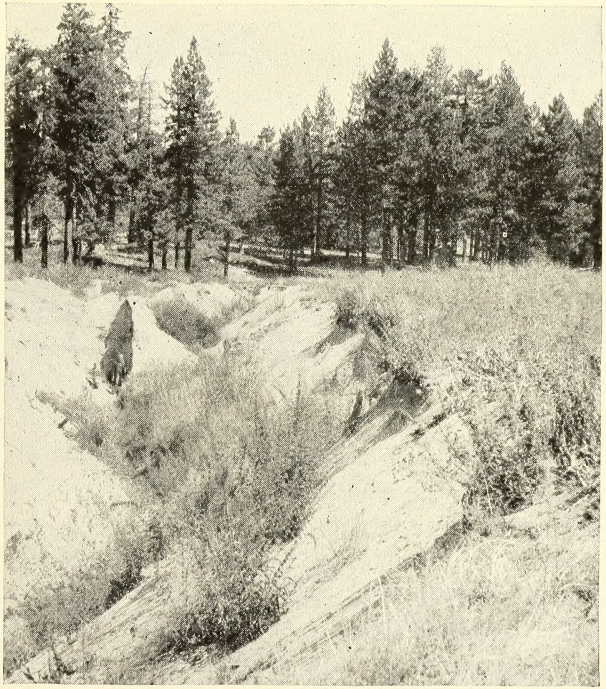


F37823

SOIL PROTECTED BY LITTER

FIG. 2.—The blanket of needles and litter beneath a dense pine wood is nature's thorough protection against erosion of soil

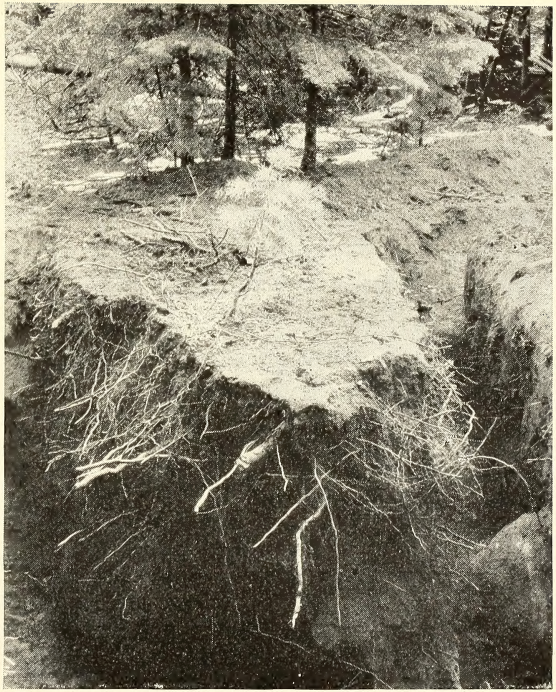
FOREST LITTER REDUCES EROSION OF SOIL



F5268

EROSION CHECKED BY WOODS

FIG. 1.—Deep gully extending up to the edge of yellow pine forest. The forest checked erosion. San Bernardino County, Calif.



F153749

ROOTS OF TREES BINDING THE SOIL

FIG. 2.—Roots and rootlets of forest trees in the soil, showing how their network binds the soil and protects it from erosion. When a tree dies the soil and subsoil become filled with hundreds of small aqueducts where the roots were. This makes the earth permeable to a great depth

ests have generalized too much from particular cases, those who rely upon mechanical means of stream control have likewise drawn their conclusions from inadequate data and from a too restricted field. At any rate it will be shown that forests, under certain conditions, have a most significant influence in determining the permanence of the development of a stream—development which enables storm water to be stored for power purposes, which to a limited extent equalizes stream flow for navigation, and which under some conditions may be of material benefit in the control of floods.[7]

Even if it were conceded, as is claimed by Mead,[8] that forests have little influence upon stream flow and the development of water resources in northern Wisconsin, and in regions of similar sandy or glaciated soils, the situation would not be the same in other regions with different soil and climatic conditions. The protective influence of the forest is of great importance in most regions subject to excessive erosion when the naked soil is exposed. In the sandy soils of the Coastal Plain region of the Southern States, where the conditions are very similar to those in the Great Lakes Region, forest influences are prevailingly at a minimum and are often negligible,[9] but these influences increase in other regions, apparently reaching their maxima, as will be shown further on, in the Sierras of California, in the southern Appalachians, and in the southern Piedmont.

The discussion in this bulletin will be restricted to erosion, the sections of the United States where it is most prevalent, the conditions of rainfall, surface and soil which cause excessive erosion, and the means of reducing it for the protection of water-power resources.

SOURCES OF SOLID BURDEN OF STREAMS

The solid burden carried by streams is derived from several sources, summarized as follows:

Farming lands, especially such as are situated on steep slopes.

Woodland and brush land in which the soil cover of litter does not afford an adequate protection.

Grasslands, especially thinly stocked prairies and the plains of the Western and Southwestern States where the sod, or sod and brush, is not sufficiently dense to protect the soil and prevent erosion.

Earth roads subject to degradation, ditches along roads, and unprotected cuts and fills along railroads and highways.

Washings of ore and clay, mine water, etc., which in place of being retained in settling basins are disposed of in waterways.

Corrasion of banks of streams.

---

which he supports by figures of run-off, that forests may have a limited influence, at the headwaters of the Mississippi River, in obstructing the run-off, and that brush land efficaciously performs the same function. POTTER, C. L. SOME SUGGESTED WAYS OF CONTROLLING THE MISSISSIPPI FLOODS. Engin. News-Rec., 94: 558. 1925. The repository of arguments for and against the benefits of forests to stream flow is a paper by H. M. Chittenden, with its accompanying discussoin. CHITTENDEN, H. M. FORESTS AND RESERVOIRS IN THEIR RELATION TO STREAM FLOW, WITH PARTICULAR REFERENCE TO NAVIGABLE RIVERS. Amer. Soc. Civ. Engin. Trans., 62: 245–318, illus. 1909. (Discussion, p. 319–546.) Unfortunately generalizations control most of the discussions. It is seldom that all the essential facts are given or that proper weight is given to different factors, and this is particularly the case in those portions of the discussion which refer to erosion of soil and corrasion of stream banks.

[7] See LEIGHTON, M. O. RELATION OF WATER CONSERVATION TO FLOOD PREVENTION AND NAVIGATION IN OHIO RIVER. *In* Preliminary Report of the [U. S.] Inland Waterways Commission, pp. 451–490. 1908. (U. S. Congress, 60th, 1st sess., Senate Doc. 325.) See also [PITTSBURGH. FLOOD COMMISSION.] REPORT OF FLOOD COMMISSION OF PITTSBURGH, PENNA. 252 pp., illus. [Pittsburgh. 1912.]

[8] MEAD, D. W. THE FLOW OF STREAMS AND THE FACTORS THAT MODIFY IT, WITH SPECIAL REFERENCE TO WISCONSIN CONDITIONS. Wis. Univ. Bul. 425: 62. 1911. (Engin. Ser., v. 6, no. 5.)

[9] ASHE, W. W. FORESTS AND THE COST OF TEXTILE PRODUCTION. 11 pp. [n. p.] [1908.]

The factors which determine the erosion of naked soils are the character of the soil and subsoil, the gradient of the surface, and the amount and character of the rainfall or other precipitation. A soil which is thoroughly granulated, even if situated on a moderate slope, is not subject to erosion. Such soils are fine gravels and coarse sands and soils of finer texture which are granulated on the surface and have thorough subsoil drainage. Soils of finer texture having a deficiency in binding material, such as river silts, loess, or other silty soils, and in the East the well-decomposed micaceous schists, are subject to excessive erosion.

The character of the rainfall is also of importance. Slowly falling rain of large total volume may, through the time allowed for percolation into the subsoil, be largely absorbed, leaving only a small amount to find its way over the surface of the soil directly into drainage channels. A much smaller proportion of the same amount of precipitation would, if concentrated, be absorbed within the same time. The greater the amount which is not absorbed, the greater is the run-off over the surface, with accompanying erosion.

According to Kennedy,[10] the quantity of silt which can be carried in suspension by a stream varies according to the square root of the fifth power of its velocity—that is, the possible silt burden increases at a much higher rate than the velocity. In case the velocity of a stream is 2 miles an hour and it is increased during flood period to 4 miles an hour, the quantity of silt which it can carry increases six times. Consequently the capacity of a stream for carrying silt increases enormously during flood periods. Corrasion of banks or channel continues to take place until the maximum silt burden for the velocity is reached. When there is a slacking in velocity for any reason, as when there are pools, or when the stream spreads out over a flood plain, a portion of the silt is deposited. But before a particle is in suspension it must be freed from associated particles either upon the surface of the land, upon the stream bank, or at the bottom of the channel. As a rule a particle must become a part of a bed load before it passes into suspension. So erosion as a rule is determined initially by the capacity of a stream for bed load. The weight of bodies such as sand, gravel, or stone, which can be rolled along the bed of a stream, varies with the velocity of the current,[11]

---

[10] KENNEDY, R. G. THE PREVENTION OF SILTING IN IRRIGATION CANALS. Inst. Civ. Eng. [England], Minutes Proc. (1894/95), 119: 281–290, illus. 1895. Kennedy's formula was based upon studies of canals. Studies upon Texas streams made by R. G. Hemphill, associate irrigation engineer of the Department of Agriculture, seem to show approximately the same percentage of silt, 1.3 by weight, being carried on the Brazos River at Waco by velocities which ranged from 0.69 up to 7.50 per second, and from the surface nearly to the bottom. The fineness and character of the silt is a factor. His investigations do not seem to bear out for Texas conditions Kennedy's statement "that corrasion continues to take place until the maximum silt burden for the velocity is secured." Undoubtedly considerable additional study of this problem is necessary.

[11] MERRIMAN, M., and MERRIMAN, T. TREATISE ON HYDRAULICS. Ed. 10, rev., pp. 294, 339. New York. 1916. According to Merriman the weight of bodies which can be rolled along the bed of a stream varies as the sixth power of the velocity of the current.

GILBERT, G. K. THE TRANSPORTATION OF DÉBRIS BY RUNNING WATER. U. S. Geol. Survey Prof. Paper 86: 10–11. 1914. Gilbert has given the subject thorough study in the laboratory, but states that the results of his investigations are to be regarded only as a contribution to the subject. In discussing the laws which control the movement of the bed load he makes the following general statement: The capacity of the stream to transport débris along its bed is affected by the width of the stream, a broad channel carrying more than a narrow one, by the velocity of the current, the quantity varying greatly for small changes in the velocity along the bed. Bed velocity is affected by slope and depth, increasing with each factor, and depth is affected by discharge and also by slope. The size of the transported particles is a factor of great importance, a greater weight of fine débris being carried than of coarse. But capacity of a stream to transport is less sensi-

and for each combination of width, slope, and discharge there is a limiting coarseness of débris above which no transportation takes place. The rate of flow increases with the volume or the depth of the water in the channel. These laws of flow and of the carrying capacity of water at different velocities of current explain the great amount of erosion of soil which takes place in regions of heavy or concentrated rainfall, such as the mountains of California, the Southwestern States, and the southern Appalachian and adjacent Piedmont regions, regions not only of concentrated rainfall, but of broken surface where it is possible for surface run-off to gather into rapid torrents having great volume and enormous cutting and carrying capacity.

The more thorough the cultivation of farming lands, the deeper the plowing, the more humus incorporated, and the better the granulation and the absorptive capacity of the soil, the lower will be the proportion of rainfall which runs off and the less will be the extent of the erosion. This is a matter of prime importance to the farmer as well as in connection with reducing the turbidity of streams, since, in addition to the physical destruction of land through the formation of gullies by erosion, the muddy effluent bears away the lighter and more fertile parts of the soil, resulting in its constant depletion. At the same time the loss of water which should soak in and be stored in the subsoil for future dry-season needs is often equally serious. Although agricultural lands contribute but a relatively inconsequential part of the total solid burden of most of our great rivers, except in the Southeast, on the whole the wastings from the agricultural lands represent the element of greatest fertility, the humus, the organic components, containing particularly the nitrogen or ammonia compounds. It has been computed[12] that an average of more than 850 pounds of soil are yearly washed from every acre of land on the Yadkin River above Salisbury, N. C. Of this more than 125 pounds are organic matter, the balance being mineral soil. The organic matter is humus, chiefly from farming soils, and where this is the case it must be replaced.

In woodland, erosion is due chiefly to the exposure of the soil through the destruction of the humus and leaf litter by fire or other agency. A forest soil as a rule has excellent subsoil drainage due to root penetration, and the top soil is usually well granulated. Moreover, there is a prevailingly good binder of rootlets. (Pl. 4, figs. 1 and 2.) For these reasons, even when the leaf litter is annually destroyed, erosion is seldom so disastrous as it is in the case of a soil used for farming, or which has been farmed and abandoned.

In open parklike woodland and brush land, such as exist in sections where the rainfall is not sufficient to support a dense stand of trees, as is particularly exemplified on the lower mountains of the West and Southwest, the litter and leaves which accumulate are not sufficient to cover the soil and afford it adequate protection. Under

---

tive to changes in fineness of débris than to changes in discharge or slope. If slope remains the same velocity changing with discharge, capacity for transportation varies with the 3.2 power of the velocity. If discharge remains the same, in which case velocity changes with slope, capacity varies with the 4.0 power of the velocity. If depth remains the same, the velocity changing with simultaneous changes of slope and discharge, capacity varies with the 3.7 power of the velocity.

[12] ASHE, W. W. TERRACING OF FARM LANDS. N. C. Geol. and Econ. Survey Bul. 17: 22. 1908.

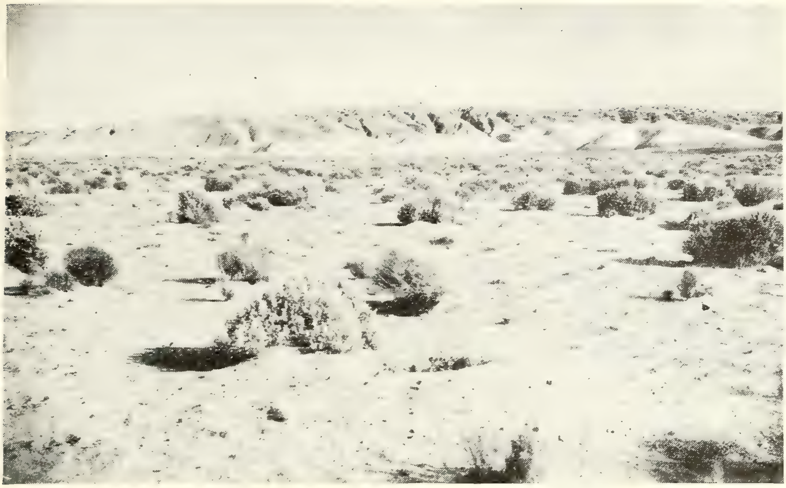
such conditions and with a concentrated rainfall, or with the rapid melting of snowfall, erosion is active. Since it is not possible to maintain in such sections forest or brush growth of sufficient density to produce adequate litter, it is not possible to reduce erosion of soil below a certain amount, the amount which is fixed by the heaviest litter which can be maintained. (Pl. 5, figs. 1 and 2.)

On the western plains there are extensive areas of unconsolidated soils protected only by a scant stand of grass, with scattered bushes intermixed. Notwithstanding that these lands are nearly level, erosion from them is often excessive. Where the grass cover has deteriorated through excessive grazing, a regulation of range practice may have the double beneficial influence of checking further range depletion, and at the same time, by inducing the more thorough covering of the soil, of lessening erosion. There are undoubtedly extensive areas in Texas and Oklahoma where this condition prevails.

Ditches along roads and cuts and fills along highways and railroads, especially in the Southeastern States where the rainfall is heavy and where grass does not readily set, contribute a large quantity of solid matter to the streams. By the use of Bermuda and carpet grasses in ditches, and these grasses and Japanese honeysuckle on embankments and slopes, much of the erosion from these sources could be prevented or at least greatly reduced. The rapidity with which erosion takes place in roads in the Piedmont and mountain sections of the Southeastern States is shown by the hundreds of miles of hollow roads in this section. A good example of road degradation through erosion is shown in Plate 6, Figure 2, and the deeply washed ditches on either side show the process by which it takes place. The brush in the ditch is the futile means employed to check it.

Friction between the current and the bank is a factor in the corrasion of banks of streams. Corrasion continually takes place, especially during periods of high water, whether resulting from rainfall or from melting snow. It is most active, however, in the streams flowing through the regions of the Great Plains. This results in shiftings of stream channels, which is particularly characteristic of the Missouri, the Arkansas, the Kansas, the Canadian, the Red River, and many of their tributaries. Corrasion is also not uncommon along many eastern streams. It is aggravated in instances by the clearing away from stream banks not only of all trees but of shrubs as well. Upon the decay of their roots the natural soil binder is destroyed. (Pl. 4, fig. 2.) The small roots and rootlets of willows, birches, alders, cane, and similar trees and shrubs grow to the very water's edge. They are often exposed along the banks of the stream and form a loose basketry often quite as effective in bank protection as ripraps.

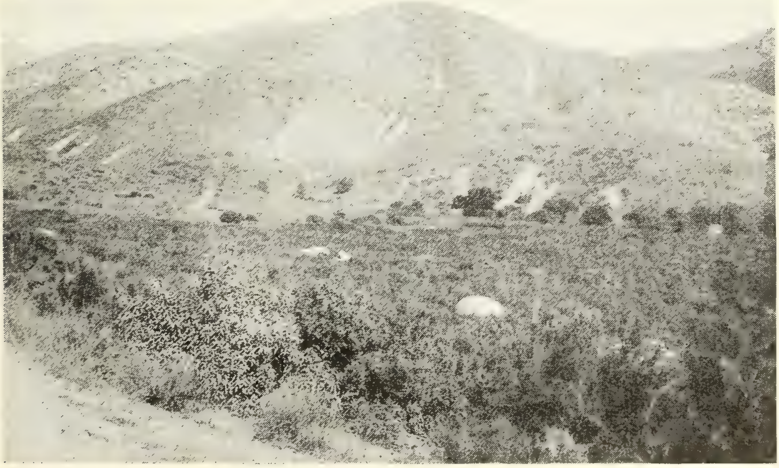
In the aggregate the solid burden which is added to streams through the washings of ore, clay, etc., is not large in comparison with the turbidity which comes from other sources. Locally, it is of importance. This contamination of streams is sometimes permitted as a result of a sentiment opposed to interfering with the conduct of local industries. Waste of this kind which is deposited in streams must frequently be removed, often at public expense, from navigable channels or from reservoirs within which it has been deposited. In some States, as in California, there are restrictions against such pollution.



F91914

EROSION OF NAKED MOUNTAIN SLOPES

FIG. 1.—Naked mountains and plains, Apache County, Ariz.



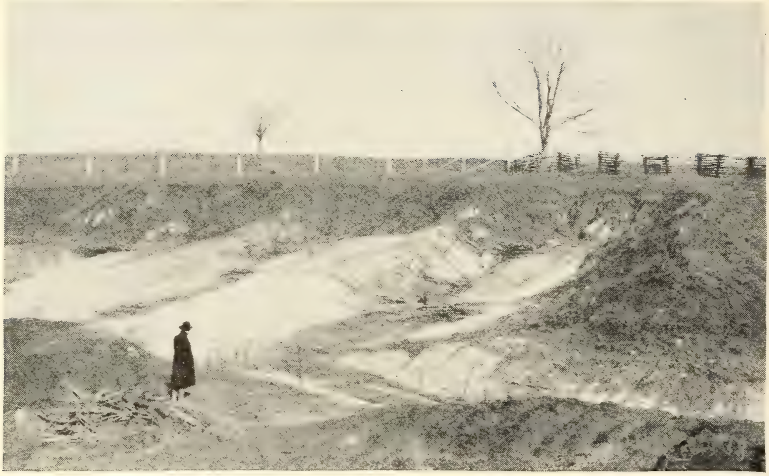
F31102A

EROSION OF SCANTILY PROTECTED MOUNTAIN SLOPES

FIG. 2.—Gullied and eroded slopes, brush-covered mountains, San Diego County, Calif.

WHERE EROSION OF SOIL CAN NOT BE PREVENTED

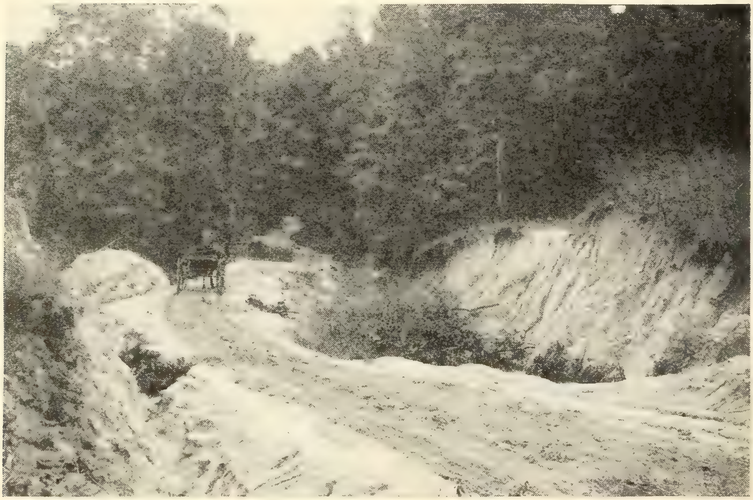
Typical of much of the country of western Texas, New Mexico, Arizona, and parts of southern California. Long periods of drought limit vegetation to a scant herbage and hardy shrubs. Consequently much of the surface is exposed. At intervals there are torrential rains, and when these occur erosion is disastrous



F40065A

EROSION OF EARTH ON FARM

FIG. 1.—Badly eroded farming land, with brush dams across the gullies, the naked slopes planted to locust switches



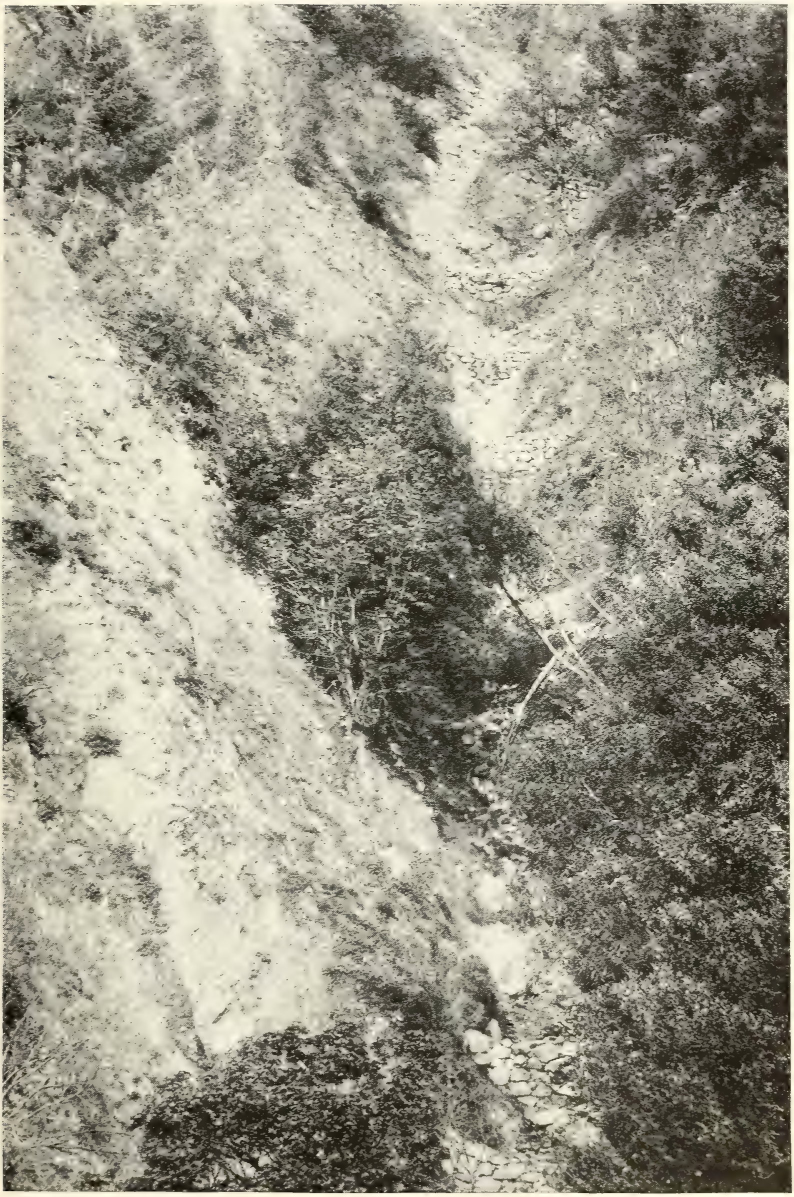
F39319A

EROSION OF EARTH ALONG ROAD

FIG. 2.—Millions of tons of earth from the "hollow" roads of the South half choke the streams. Brush placed in a ditch, which through neglect has become a gully, in a futile effort to check washing away of the road

SOURCES OF SEDIMENT WHICH FILLS RESERVOIRS

If the life of a reservoir is 50 years, the users of power should pay for it in that period. If on account of erosion it is only 25 years, the annual payments must be twice as much



F30931A

INEFFECTIVE ATTEMPT AT PREVENTING EROSION

Masonry dams in the mountains of southern California designed to check torrents, reduce erosion of soil, and promote absorption of rainfall. Note scanty soil cover in places and erosion on slope where the soil cover is thin or wanting. Thirty-eight hundred of these dams have been built and the results show that the work has considerable value in promoting absorption of water on the level benches, but is largely futile in so far as reducing erosion on unprotected slopes

PLATE VIII

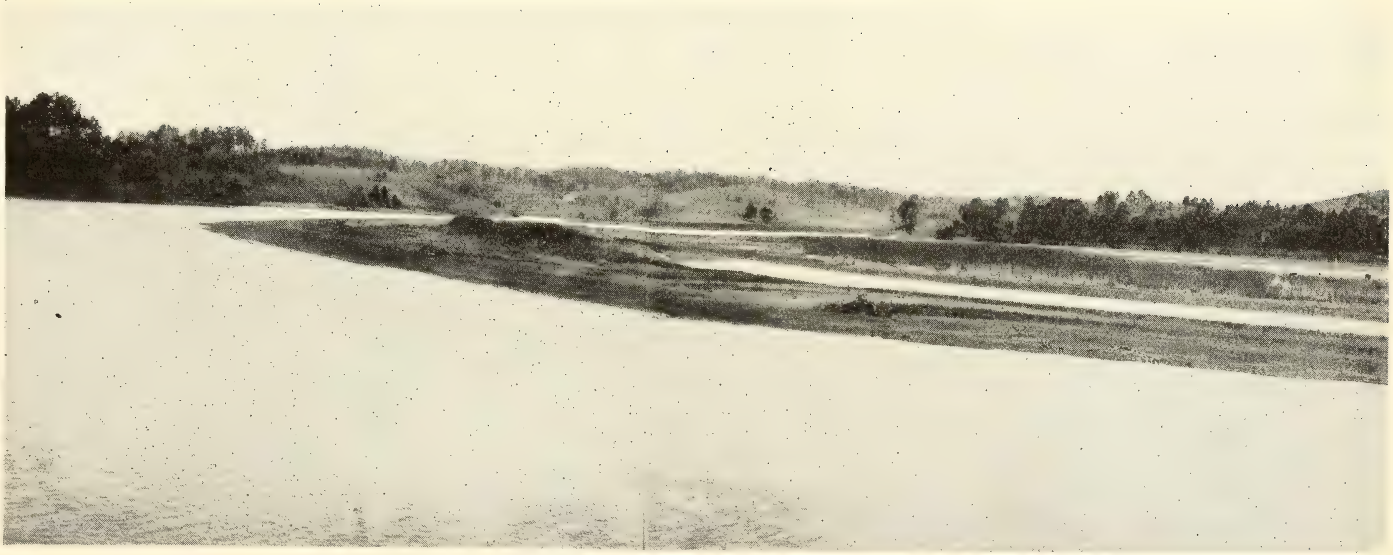


PHOTO BY S. W. M'CALLIE, STATE GEOLOGIST OF GEORGIA

PONDAGE REDUCED THROUGH SILTAGE

Silt beds filling the upper end of Bull Sluice Reservoir, Chattahoochee River, Ga., and greatly reducing the pondage. These deposits have been built up by the most fertile soil washed from thousands of hillside farms

RELATIVE VALUE OF FOREST AND OTHER COVER IN REDUCING EROSION OF SOIL

It is sometimes claimed that any other ground cover or even masonry dams will adequately replace the forest as a protective agency. (Pl. 7). In the case of brush the protective efficiency may be as great as that of the forest; but brush provides no merchantable products such as woodland produces and is therefore uneconomical. In the case of grass, it is more than doubtful if its protective efficiency is as great as forest in the Rocky Mountains, south of Idaho, and in the southern Appalachian and southern Piedmont regions which are the regions where protection is most urgently needed. In these regions there are many types of soil and many sites—warm and dry southern slopes—on which a permanent sod can not be maintained. To be handled as a profitable investment on such sites, grass must be reset at frequent intervals. At such periods the naked soil is exposed for several months. In contrast, the continuity as well as the completeness of the protection afforded by woods, if fire is kept out, is of the highest value.

Another advantage of the forest is the greater permeability of the soil—the deep-root zone, 3 to 4 feet, penetrated by the many channels resulting from the decay of roots and rootlets as far down as the roots extend. The influence of the roots of trees is evident wherever a new road is cut through a forest; for along the sides of such new excavations during wet weather streams of water can be found trickling and even spouting from root holes as far down as 3 or 4 feet below the surface.

The statement has been made by Mead[13] that the forest cover exercises no influence on permeability. This may be largely true of sandy and glaciated soils, such as he had under observation in northern Wisconsin, and it probably holds true for such soils independent of location. One of the steadiest small streams in the Eastern States is Hitchcock Creek, Richmond County, N. C., a sand-hill stream with little vegetative cover on the stream basin but with a highly absorptive soil. A test which was conducted a few years ago by the author shows the comparative permeability and depth of the root zones of the forest and grassland, and yields results of most positive significance. Adjoining areas of forest, old grassland, and old farm land, with the same slope and aspect, were selected, and during the winter, when transpiration of moisture by the forest was largely eliminated as a factor, measurements were made of the moisture content of the surface soil and of the subsoil at 3 feet. The forest soil during the winter was invariably the most dry, showing the greater permeability. The subsoil of the grassland, deficient in root drainage, was usually wetter than the forest soil, also the surface soil of the grassland was often wetter. Both surface soil and subsoil of the naked land were always wetter than those of the near-by forest, except where the naked surface soil had been dried out by high wind. Newly cleared land, however, exhibited nearly the same conditions as that bearing forest trees.

Of all surface covers which can be employed in reducing soil erosion the forest is the most efficient and most permanent. The mat of leaves and humus forms an uninterrupted cover, and the deep roots render the subsoil very permeable to water.

---

[13] See footnote 8.

COST AND VALUE OF REDUCTION IN EROSION THROUGH FOREST PLANTING

In the Southeast there are already many reservoirs which have in whole or in part lost their storage capacity through silting because the catchment basins were not so protected as to prevent erosion of the soil (pl. 8); but, as has been pointed out, excessive erosion of soil is not a normal condition, and the fact that certain reservoirs have been impaired by siltage in no way reflects upon the value of storage reservoirs well located, and for which, if they are efficiently protected, permanence can be assured.

In the regions of deleterious erosion it is desirable for the hydroelectric engineer who contemplates complete development of water resources—that is, the utilization of storm water by storage—to have the benefit of a protective cover for impounding basins. It is not a difficult matter to compute, on the one hand, the relative value to a community of farm land of comparatively low productivity and on the other hand, that of the same land in forest supporting a permanent forest industry and affording the assurance of permanent power for nonforest industries. This permanency of additional power, obtained through storage of water, may in itself far more than offset the loss of the use of the land for agriculture. Water-power resources are essential to the continued future development of a region.

There are undoubtedly cases where it would be desirable to go to the expense of protecting the surface of land by forest planting in order to obtain a reduction in erosion. In considering a policy of planting to protect the surface, those lands should be selected first which are eroding at the most rapid rate and which are so situated, that the detritus from their surface is deposited most directly in the reservoir.

In case lands can be acquired below certain prices, these prices varying in proportion to the earning capacity of the lands, it will be possible to plant them to forest with the expectation that the growth of timber will pay or more than pay the carrying charges and interest on the investment in planting. The lands which are most urgently in need of planting are largely either idle farm lands or farm lands which are being cultivated and consequently are comparatively high priced. Frequently the combined cost of land and of planting is so high that the returns in timber probably would not be equal to the current rate of interest. In case it is found that the land can not be acquired at a price which will justify the purchase for growing timber alone, it may be possible to meet the increased costs by investing an amount which represents the capitalized value of the enchanced or lengthened utility of the reservoir.

AN EXAMPLE

A reservoir has an initial utility value for storage of $2,000,000 or 32,000,000 kilowatt hours a year, the cost of storage being well within the limits of profits on the investment. It is determined that the turbidity of the impounded stream and the rate of deposit of silt in the reservoir are such that three-fourths of the storage capacity, or 24,000,000 kilowatt hours of potential power a year, will be lost within 40 years. To what expense, if any, would the owner of the water rights be justified in going so that at the end of 40 years the reservoir would have three-fourths of the storage capacity or 24,000,000 kilowatt hours of power a year? (Fig. 1.)

In case erosion should continue unchecked, at the end of 40 years there would remain only 25 per cent of the initial utility value or 8,000,000 kilowatt hours a year. The utility value is irrespective of whether amortization of the investment has been effected in whole or in part. The question then is: What sum could be expended by the owners of the reservoir, assuming that the purchasing power of the dollar remains unchanged, to give assurance of a utility value of $1,500,000 at the end of 40 years? This would be three-fourths of the original utility value, whereas, if erosion continued unchecked, there would remain a utility value of only $500,000. (Fig. 2.)

For the sake of greater simplicity and clarity it is assumed: That it would be possible to plant in one year all denuded lands the erosion from which is most serious, such planting taking place possibly during the construction of the reservoir so as to obtain immediately the continued full benefits of its lengthened utility; (2) that the rate of sedimentation in the reservoir proceeds at a constant rate until, except for the channel of the stream, it is completely silted up; and (3) that the utility value is abruptly decreased by one-fortieth at the end of each year. Actually, however, such a rate of silting is not constant. Sedimentation takes place at a diminishing rate as the reservoir fills in, as the area of slack water diminishes, and as the general current of the water through the reservoir increases; and the rate of sedimentation is also subject to great variation due to the occurrence of high floods or to long periods of even flow, and on account of eddies and convective currents the deposit as a rule is irregularly distributed.

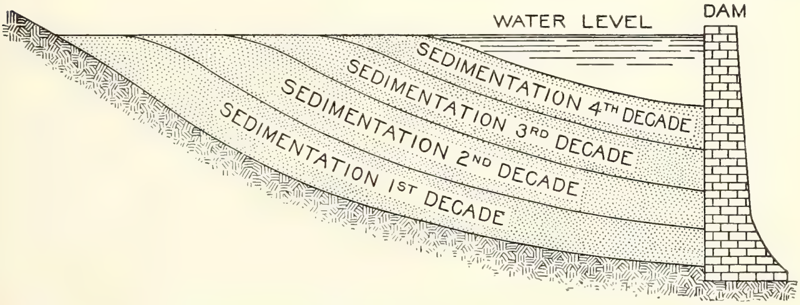


FIG. 1.—Decrease in storage capacity of a reservoir by decades, due to silting, schematic

As a result of planting, there is assurance of a utility value of $1,000,000 at the end of 40 years which otherwise would have been lost. Without planting, this value would have been gradually reduced year by year through the period of 40 years so that at the end of that time none of it would have remained. Consequently there would be a consecutive loss of storage capacity at the end of each year for 40 years. This loss would have an average annual value of $25,000 or 225,000 kilowatt-hours a year. Assume that by immediate action this loss is prevented. The storage capacity thus preserved would at the beginning of the year have a value equivalent to a sum which, placed at interest at the current rate, would amount to $25,000 at the end of the year. The present value of such storage capacity as would have been lost at the end of the fortieth year would be equivalent to that sum which, put at interest at the current rate, would then amount to $25,000. There would be corresponding values for the losses of the intervening years. The sum of these amounts would be the present value of the extended life of the reservoir which would result from planting. On this basis the present value of the storage capacity having a utility value of $1,000,000 at the end of 40 years would be $353,646. (Fig. 3.)

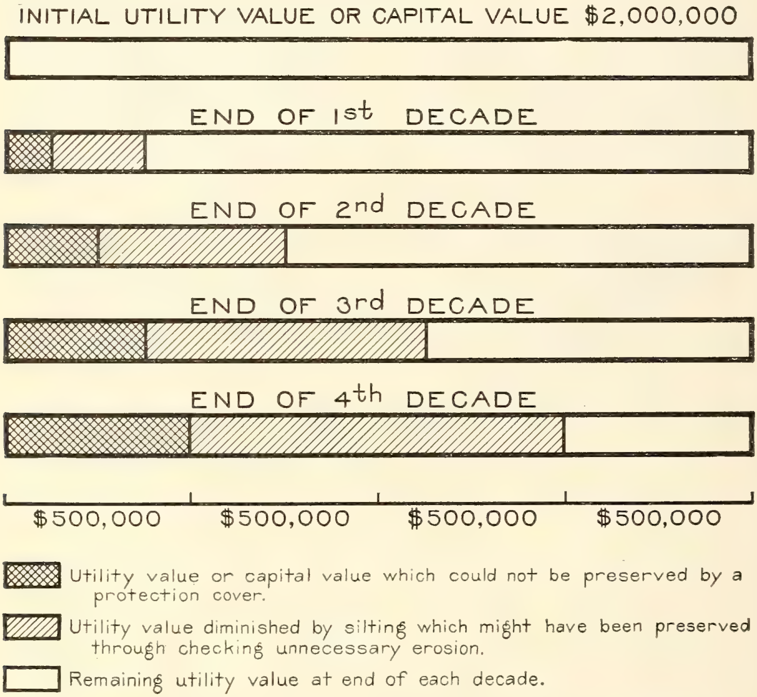
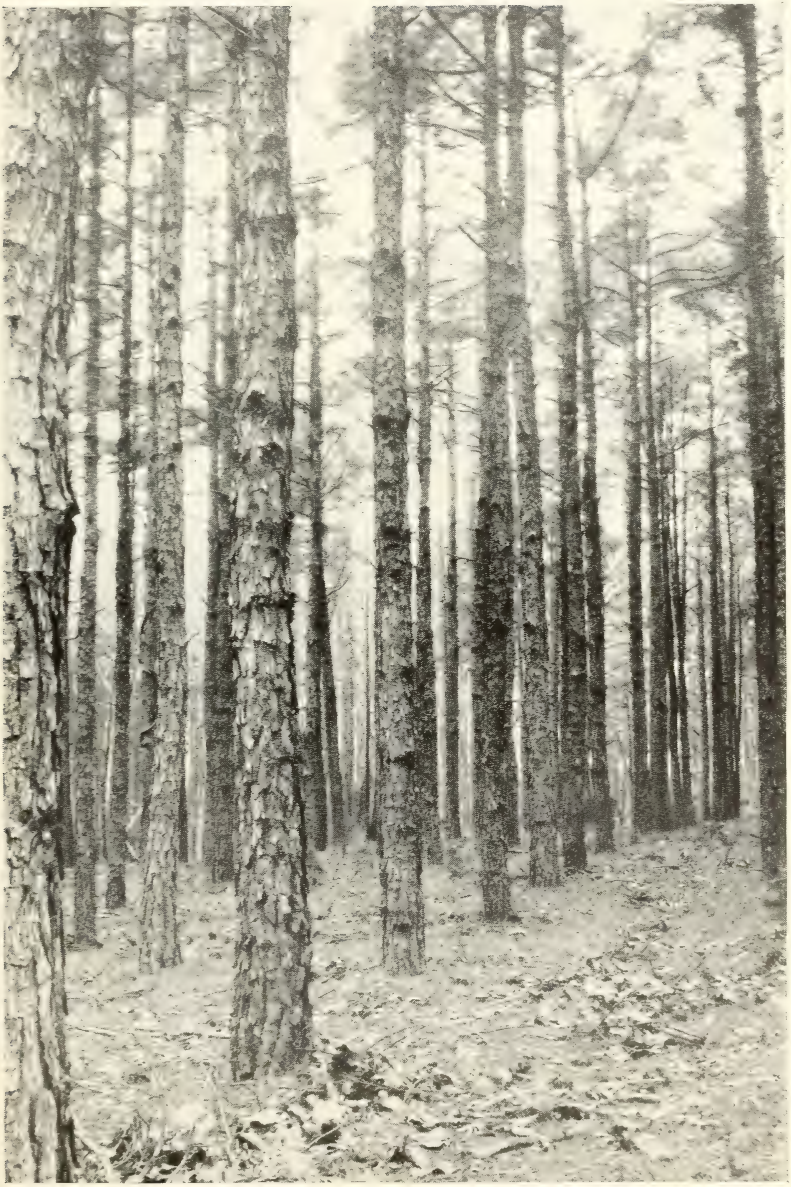


FIG. 2.—Decrease in utility value or capital value of a reservoir through silting

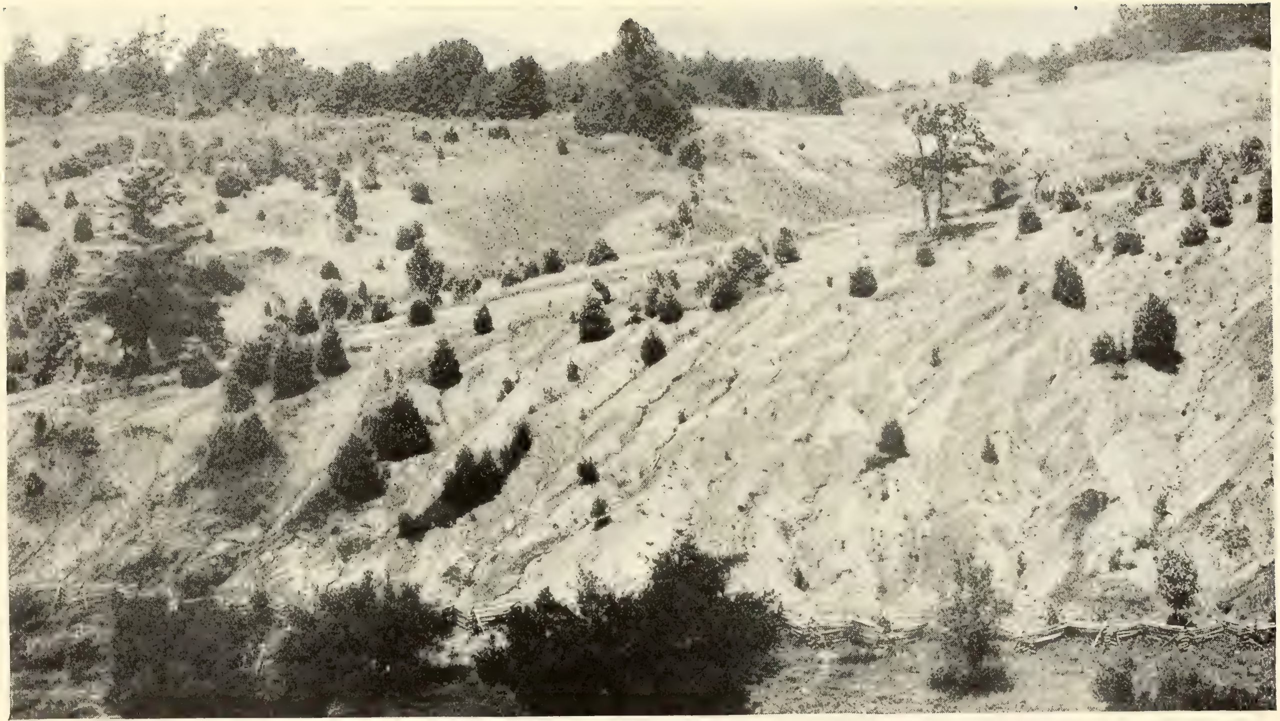
In this hypothetical case a location in the Piedmont region of the Southeastern States may be assumed and the short-leaf or rosemary pine of that region may be selected as a tree for planting. An examination of the basin shows that the denuded lands from which the larger portion of the turbidity is derived are, if planted in short-leaf or rosemary pine, of forest-producing quality No. 2. Without thinnings or other care than protection against fire and insects, a yield of 17,100 board feet, measured by the Scribner log rule, and 18¾ cords of merchantable wood, but of a size too small for saw



F185509

HOW TO MAKE THE RED HILLS PROFITABLE

Plantation of 10 acres of native pine 35 years old, Spalding County, Ga., cutting about 17,000 feet per acre. Red clay soil, hill country of southeastern Piedmont



F25374

WHERE EROSION OF SOIL CAN BE PREVENTED

Badly gullied hillsides. Natural restocking beginning to take place. This should be supplemented by planting to establish a protective cover for the soil timber, can reasonably be expected at the end of 40 years from such a site. (Pl. 9.)

The present general value of the timber of this tree in stands 40 years old is about $3.50 a thousand board feet, log scale. During the past 40 years, timber of this kind has increased in value at the rate of about 5 per cent compounded annually, or from about 50 cents to $3.50 a thousand board feet (disregarding the shrinkage in the purchasing price of the dollar). In case timber of this kind, instead of continuing to increase in value at a rate of 5 per cent, should increase at a rate of 4 per cent during the next decade, and at a continually declining rate each subsequent decade to the end of the 40-year period, so that the average rate of increase for the entire period would be 2.6 per cent compounded annually, its value at the end of that time would be $9.51 per thousand board feet. (Fig. 4.) It is believed that the rate of increase will as a matter of fact greatly exceed this. Cordwood of a character suitable for paper-pulp stock will probably have a value of not less than $2 per cord at that time. There could thus reasonably be expected from planted stands a gross return of $200 per acre (the computation shows $200.12), of which approximately $163 would come from the sale of saw-timber stock and the remainder from the sale of cordwood. Such figures undoubtedly seem extremely high, but they are not out of proportion to the increase in the value of timber of the same class which has already taken place in Maryland, and are at a considerably lower rate than the increase in value which has taken place in the case of second-growth white pine in New England.[14] Taxes on such land can be assumed at 20 cents an acre a year, totaling, with interest at the current rate of 6.5 per cent a year, $36.66 at the end of the period of growth; while the cost of protection can be assumed at 3 cents an acre a year, likewise compounded at a rate of 6.5 per cent for 40 years, totaling $5.50 per acre. If these two items of expense, amounting to $42.16 are deducted from $200.12, the estimated total gross receipts from the sale of the timber, there is a balance of $157.96.

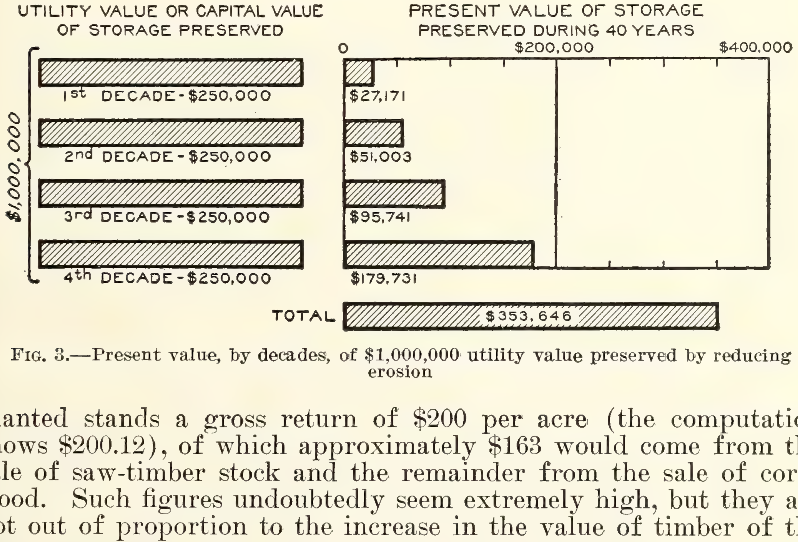


FIG. 3.—Present value, by decades, of $1,000,000 utility value preserved by reducing erosion

---

[14] During the last 25 years second-growth white pine in middle New England has increased from $2.70 a thousand board feet in 1899 to $14 per thousand board feet in 1924, or at a rate of more than 6.5 per cent compounded a year.

An initial investment of $12.50, at a rate of interest of 6.5 per cent compounded annually, will amount to $157.96 at the end of 40 years. Consequently the owner of water rights would be justified in going to an outlay of this amount per acre for the purchase and planting of lands with the expectation that the sale of the products from this land would return the initial investment and would cover the interest on this outlay at a rate of 6.5 per cent per annum compounded.

There are areas of denuded lands on which restocking to trees could be expected, at least in part, from seed scattered by near-by old pines. There are other lands which would require planting, either because it would be necessary to check erosion at once or because there are no near-by seed trees. (Pl. 10.)

An average present figure for planting short-leaf pine in this section, including the growing of 2-year-old stock, would be about $8 per acre. Many and in fact most lands requiring planting for their protection have recently been in cultivation. On such lands it would be possible without difficulty, by means of a large bull-tongue plow or shovel plow with coulter attached, to lay off rows within which planting could be done. This would cheapen the cost of outsetting.

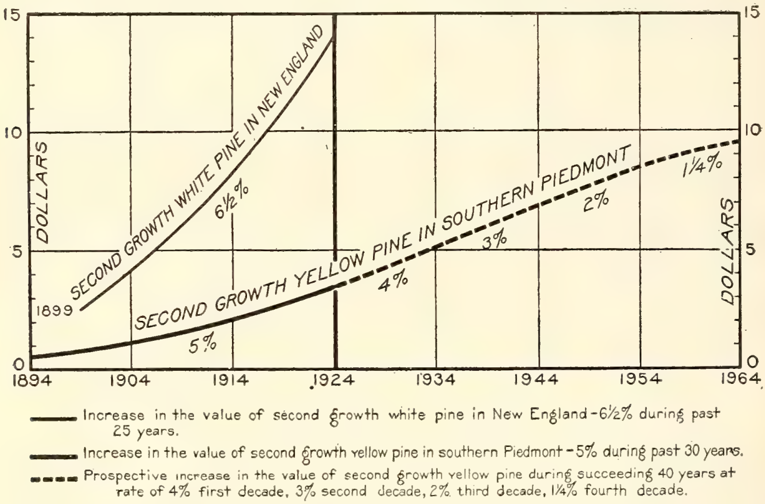


FIG. 4.—Rate of increase in value of second-growth pine timber in New England and southern Piedmont region

At a cost of $8 per acre for planting there would remain of the $12.50 only $4.50 an acre to be applied to the initial cost of the land. It would be necessary that the remaining expense of purchasing the land be charged as an element of cost in maintaining the utility value of the reservoir. The fund of $353,650, given above as representing the present value of the additional utility of the reservoir at the end of 40 years, can be drawn upon for the balance of the money necessary to complete the purchase of the land and to protect it from fire.

An examination of the basin of a stream might show that practically all of the erosion, including the heaviest portion of the solid burden which enters the reservoir, consisting of the large sand, the small sand, and the coarser silt, is derived from approximately 6,000 acres of steep land now being cultivated annually to tilled crops, and that there are in addition 4,000 acres of land the erosion from which is less serious, but on which erosion should be checked within a period of not more than five years.

It is ascertained that the 6,000 acres can be acquired at an average price of not more than $15 an acre and can be planted at a cost of not more than $8 an acre. These lands, being hilly, are of low productivity in farm crops but are of good productivity in timber. In addition to expending $12.50 an acre, which represents the value of the land when planted for timber production, it would be financially advantageous to expend a sum not exceeding the $353,650 mentioned above.

An examination of the 4,000 acres on which erosion is less active might show that natural seeding from near-by old trees could be expected to restock this land in forest growth within a period of five years, and that consequently it would be unnecessary to resort to the expense of planting, so that the purchase price of the land, allowing for natural restocking, would be within the investment value of the property in growing timber.

SETTLING BASINS

In addition to planting, it is possible and even desirable in some places to employ settling basins, within which much of the heaviest material at least may be left by natural elutriation. For this purpose, rough alluvial lands should be selected which have been injured by gullying during floods or upon which sand or gravel bars have been deposited. By means of low and inexpensive dams such lands can be flooded. The deposit from the slow-moving water will, in a few years—the period varying with the amount of sedimentation height of dam, and rapidity of current—reach the top of the dam, except in the stream channel. The dam will then have performed its function. Settling basins are therefore a temporary expedient. They may be employed with a view to preventing loss in storage capacity of the reservoir while a planting program is being worked out and executed. (Pl. 11.)

Lands built up by means of a settling basin may be made valuable for farming purposes by the removal of a portion of the dam at one point so as to permit the stream again to seek its normal or former channel bed. Soils so deposited are free from stone and gravel and enriched by the sedimentation from the slack water. Deposits of this kind frequently fringe the entire upper margins of large reservoirs. Such, for example, are the deposits in the reservoir at the Muscle Shoals[15] development, which in places would now be suitable for agricultural use if the water table were lowered only a few feet. Artificially formed alluvials of this kind after the removal of a portion of the dam are level and would generally be above the flood line of the stream. Furthermore, they would not be subject to excessive surface erosion so long as the greater portion of the retaining dam remained intact. Their level surface, great fertility, ease of cultivation, and immunity from flooding render such lands extremely valuable for farming purposes. As the stream cuts its new channel to the depth allowed by the removal of the dam, it might be desirable to plant to stream side shrubs, the bank thus being formed, in order to prevent corrasion and restrict meandering.

---

[15] See footnote 5, reference to p. 111.

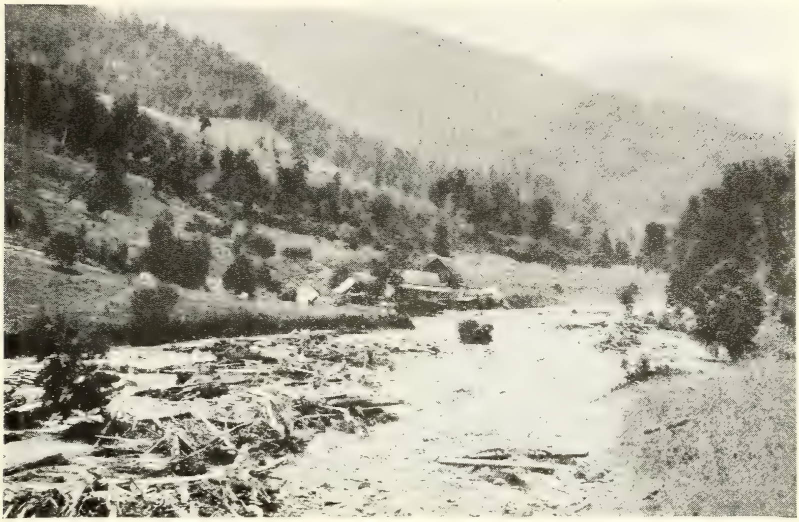
PLANTING A WOOD

In considering plans for forest planting a decision should first be reached as to the most desirable species to employ. In making such a choice full weight should be given (1) to the health and vigor of different species, (2) to the cost of propagating stock for planting, (3) to the ease of planting, and (4) to the initial rate of growth of the kind of tree from the point of view of obtaining a suitable soil cover within the shortest period. Such consideration should have as much weight as the value of the timber that would be produced by the stand within the period of growth.

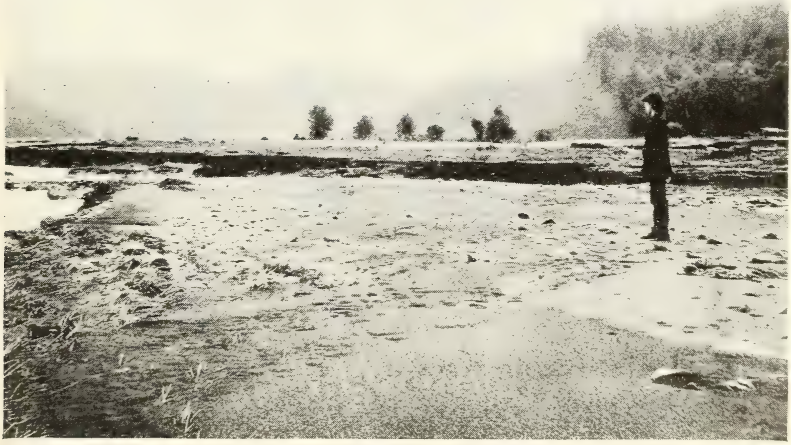
Native trees as a rule should be selected. A careful study of the site should be made to ascertain which of the native species is most suitable for the site, and the quality or productive capacity of the site for the species in question should be ascertained. For their value in growing timber, soils are classified on the basis of the number of cubic feet of solid wood of a specified kind of tree that can be produced within a given period. If other than a native species is selected, it is more difficult to decide upon these points.

The following native species are particularly to be recommended for planting for protective purposes in the sections for which designated, but they by no means include all of the desirable native species. High altitudes and particularly unfavorable sites, including very dry or stony, shady, or wet sites, demand special species.

In the Northeast, in the upper Mississippi Valley, and in the southern parts of the Lake States, the white pine is the most desirable conifer for general conditions on sites to which adapted, and when not subject to destructive diseases and pests. Norway pine is suitable for sandy or poorer sites. If a hardwood species is to be considered, red oak is unexcelled either by itself or in mixture with white pine, although the white pine as a rule will outgrow the red oak. In the Appalachians white pine is the desirable conifer for medium and higher altitudes particularly on the drier sites; and yellow poplar and red oak are the most desirable broad-leaved species. In the southern Piedmont regions and the lower Mississippi Valley and in the Ozarks shortleaf or rosemary pine on the uplands with southern red oak on similar sites and yellow poplar on moist (not wet) sites are the best suited species. In the northern Rocky Mountain region and on the northwest coast western white pine and Douglas fir can be expected to give the best results under average conditions. In the Southwest on medium sites the western yellow pine is the desirable tree, but the species, preferably a local one, should suit the site and altitude.



F30540A



F30533A

SITES FOR SETTLING BASINS

Alluvial lands, headwaters of Catawba River, N. C., injured or destroyed by floods in 1916. They represent ideal sites for the location of settling basins to collect large quantities of sediment which otherwise would reduce the pondage of reservoirs on this river. In time level alluvials very valuable for farming would be built upon the sites of the settling basins

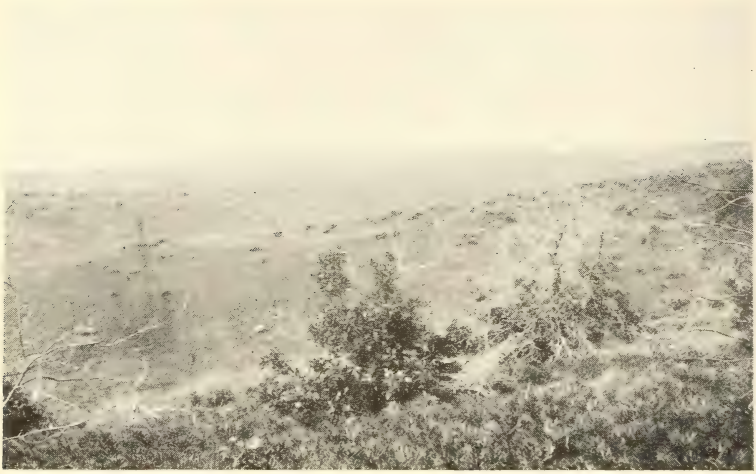


FIG. 1.—Bayfield County, Wis. Hills of coarse sand and gravel stretch to the horizon. Once heavily forested, now denuded and periodically fire swept. On account of the porosity of these soils there is comparatively little erosion. The sandy soils supplemented by lake storage result in low flood stages in the streams and high summer run-off. Typical of the Great Lakes region

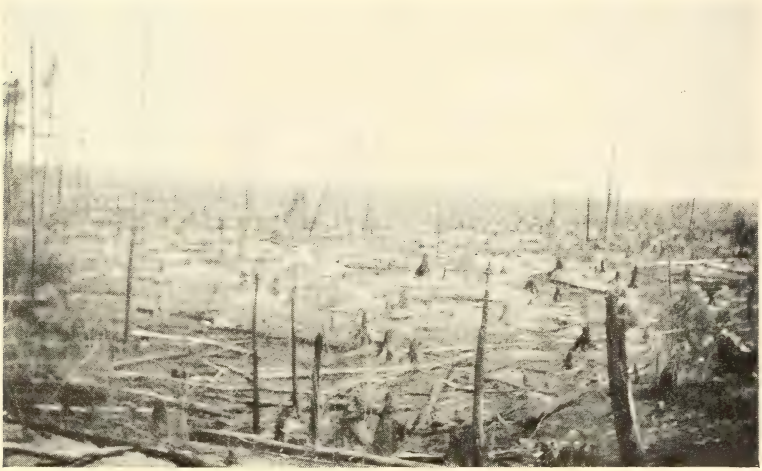


FIG. 2.—Undulating forest land with sandy soil, recently lumbered and just burned over, Marquette County, Mich. Unless protected against fire this land will soon be similar to that in Figure 1. There is, however, even when the surface is broken, little erosion on such sites, because of the porosity of the soils

FOREST INFLUENCES LOW

REGIMEN AND TURBIDITY OF THE MAIN STREAM SYSTEMS IN THE UNITED STATES

The important factors which determine (1) the volume and (2) the character of the flow of streams of the United States are:

Source of water supply; amount, character, and distribution of precipitation.
Lake storage.
Underground storage.
Character of surface of the basin.
Character of soil and subsoil and especially its susceptibility to erosion.

The streams of the United States may be separated into eight groups, on the basis of regimen, turbidity, and the influence of forest protection on their watersheds:

Rivers of the Northeastern States and the Great Lakes region.
Rivers of the Middle Atlantic coast region.
Rivers of the southern Appalachians.
Rivers of the eastern slope of the Rocky Mountains.
Streams rising in the plateau region of central Texas.
Colorado River and interior basin.
Sacramento and San Joaquin Rivers.
Columbia River.

RIVER SYSTEM OF THE NORTHEASTERN STATES AND THE GREAT LAKES REGION

The northeastern and Great Lakes regions embrace the rivers in the New England States, the Hudson River, the rivers in the region of the Great Lakes, and the headwaters of the Mississippi. The basins of the streams of the northeastern region are well forested as a rule or their surfaces are well covered. The natural permeability of the soil depends largely upon texture and structure, and the absorptive and water-holding capacities are increased by a good humus content. Many of the soils of this general region are of such character as to accumulate and maintain a liberal quantity of organic matter. The freezing of the soil during a considerable period of the year not only protects it from erosion but also retards the oxidation of its humus. The humidity is relatively high and the evaporation low. An extensive system of lakes acting as natural reservoirs, at the heads of many of the large rivers, is instrumental in furnishing an equable stream flow from a moderate but evenly distributed precipitation of 30 to 40 inches, which in winter occurs largely as snowfall, and which passes off as spring freshets after warm rains. Dams at lake outlets increase storage. Natural storage is also favored by the deep glacial drift and the spongy moss and deep humus. Except on very sandy soils, sod naturally sets in ditches, on stream banks, and in waste places, and forms nearly as perfect a protection against erosion as the forest cover. Erosion is slight and the silt burden of the streams is insignificant.

The Kennebec River may be taken as a type of the streams of the northeastern group. The tidal estuary which forms its mouth is free from silt bars, and this indicates the small quantity of solid material which it bears. In the discussion of Portland Harbor by the Chief of Engineers,[16] the statement is made that "There are no silt-bearing streams emptying into Portland Harbor, and the improved depths obtained * * * will be practically permanent." Although many of the New England streams carry silt, the burden is small when compared with that of southern and southwestern streams.

---

[16] MACKENZIE, A. IMPROVEMENT OF RIVERS AND HARBORS IN MAINE AND NEW HAMPSHIRE. [U. S.] War Dept. Ann. Rpt. 5: 33. 1906. (Rpt. Chief Engin., U. S. Army.)

The high spring freshets resulting from the melting of the accumulated winter snows are followed by well-maintained midsummer flow. The relation between the minimum flow and the maximum flow is less than 1 to 100. The Connecticut River is the least steady of the streams of this group in its flow, because a large portion of its basin is located on the steep slopes of the White Mountains and other mountains of northern New England, and because of the comparatively small lake surface.

The Hudson River is similar in general characteristics to the New England streams; but its chief tributary, the Mohawk, drains a thoroughly cleared agricultural valley, and during freshets bears a moderate silt burden. That portion of the river above Troy which comes from the Adirondacks nearly duplicates in general character the streams of Maine. The silt burden of the Hudson, which has increased with the extension of the cleared area, amounts to 240,000 tons a year, a larger quantity than is borne by the rivers of New England, with their better-forested watersheds and better-granulated soils, but smaller than that carried by the large rivers of the southern Appalachians.

The streams of the Great Lakes region, which include the headwaters of the Mississippi River, with the St. Croix, Wisconsin, Chippewa, and most other rivers of Wisconsin, Minnesota, and northern Michigan, are similar to those of New England in lake feeding, but the soils are more sandy; there is less surface relief and while the forest condition of their basins is poorer, the extent of forest influences on their flow is less. (Pl. 12, figs. 1 and 2.)

Erosion, on the whole, is so slight in this region that the Mississippi River above Minneapolis, with a basin of 19,585 square miles, has a yearly silt discharge of only 117,000 tons, compared with nearly 11,000,000 tons from the Tennessee River with less than twice the drainage area of this portion of the Mississippi; that is, the solid burden at the Tennessee River is about fifty times that of this portion of the Mississippi River.

The soils of the basins of the streams in the Lake States region are prevailingly loose and possess a high storage capacity. However, they are locally deficient in cohesion, and where this is the case the banks of even small streams corrade during the spring freshets. This produces sand bars, especially in some of the streams of Michigan, such as the Grand, Au Sable, Kalamazoo, and Muskegon Rivers. There is evidence that erosion of soil from the upland denuded of forest has contributed to these deposits, since, and especially in the southern portions of these States, there are areas of clays and loams which are subject to erosion whenever the surface gradient is suitable, although the general setting of grass, the long winters, and the moderate summer rainfall contribute to reducing it to a minimum.

Extensive areas in the Lake States are of only marginal value for farming, but have been cleared for that purpose. After a futile attempt at cultivation, the greater portion of these farms have been abandoned. Few of these abandoned lands restock to trees, although coarse grasses, chiefly broom grasses (Andropogon) usually soon clothe them. The area of such abandoned farm lands in the Lake States is estimated to be not less than 5,000,000 acres. In addition, there are estimated to be more than 31,500,000 acres of burned or cut over and subsequently burned or devastated forest land in this region, largely destitute of tree growth but often with fair ground cover of grasses and small shrubs. Even in the most rugged regions there is a minimum of erosion on these sites because of the sandy or gravelly soils. Except locally, as in the protection of stream banks or when the soils are clayey, forest cover exercises a low protective function in most portions of the Lake States region.

In the New England States, however, the demarcation between absolute forest lands and those lands most suitable for farming is usually sharply drawn. For this reason further encroachment upon the forest lands for farms will not be extensive; and, if the forest conditions are not destroyed by injudicious lumbering, the present conditions of stream flow can probably be maintained.

RIVERS OF THE MIDDLE ATLANTIC COAST REGION

The most important streams of the Middle Atlantic coast group are the Potomac, the Delaware, the Susquehanna, the Rappahannock, and the James Rivers. There should be included with this system the Allegheny and Monongahela and certain other head streams of the Ohio which lie within this general region and exhibit similar characteristics of flow.

These streams rise in the Allegheny Mountains, where for the most part their headwaters drain narrow agricultural valleys inclosed by forested but thin-soiled though permeable shale and sandstone ridges. The lower portions of their basins are largely cleared and have rather heavy soils and frequently poor humus conditions, both in the forests and in the agricultural lands. The forest humus, derived chiefly from oak, chestnut, and pine, is naturally scant, except at high altitudes, and has been further reduced over large areas. Burning resulting in insolation of the soil and the compacting effects of heavy rains have resulted in light erosion.

Stream flow is maintained by a rainfall of from 40 to 50 inches, a feature of which is a heavy, irregular midsummer precipitation, compared with 30 or 40 inches of precipitation on the basins farther north. The considerable winter snowfall is usually removed by warm spring rains, causing floods, which corrade the banks of streams and also erode the agricultural lands. (Pl. 13.) In addition there are frequent summer and fall floods, all accompanied by a large silt burden in the streams. The floods damage canals and riparian property, and the silt is deposited in the estuary channels, where constant dredging is required to maintain depth.

The silt which is annually discharged by the Susquehanna River at Danville, above which point the basin of the river has an area of 9,530 square miles, amounts to 240,150 tons. On the James River it has been estimated [17] that, in a flood with a 10-foot crest, from 275,000 to 300,000 cubic yards of solid matter are moved during

---

[17] HAINS, P. C. IMPROVEMENT OF THE JAMES RIVER, VIRGINIA. [U. S.] Sec. War Ann. Rpt. 2 (pt. 2, app. J) : 947. 1885. (Rpt. Chief Engin., U. S. Army.)

24 hours. The discharge of sediment by the Susquehanna had become so excessive by 1871 that it was found necessary that year to abandon the Brewerton Channel to Baltimore in Chesapeake Bay, since this channel was continually obstructed by the sediment deposited in the eddy made by the currents of the Patapsco and the Susquehanna Rivers. The average turbidity of the Susquehanna is 21 parts per million, and that of the Potomac and James Rivers is higher.

A most notable power development on the Susquehanna River is the projected plant at Conowingo, where it is estimated the initial generation will render available 300,000 horsepower, and possible additions will produce 500,000 horsepower, thus placing this river in the class with the Tennessee as one of the great power streams of the Eastern States.

These streams lack the natural reservoir system of lakes which characterize the streams of New England and many of the streams of Wisconsin, Michigan, and Minnesota. They also lack the sandy or glacial soils of the northern river basins, which possess ample water-storage capacity. Moreover, the thinner humus of the oak and chestnut forests of the Middle Atlantic coast region offers only a meager water storage compared with that of the thick spruce duff and the moss of the more northern streams.

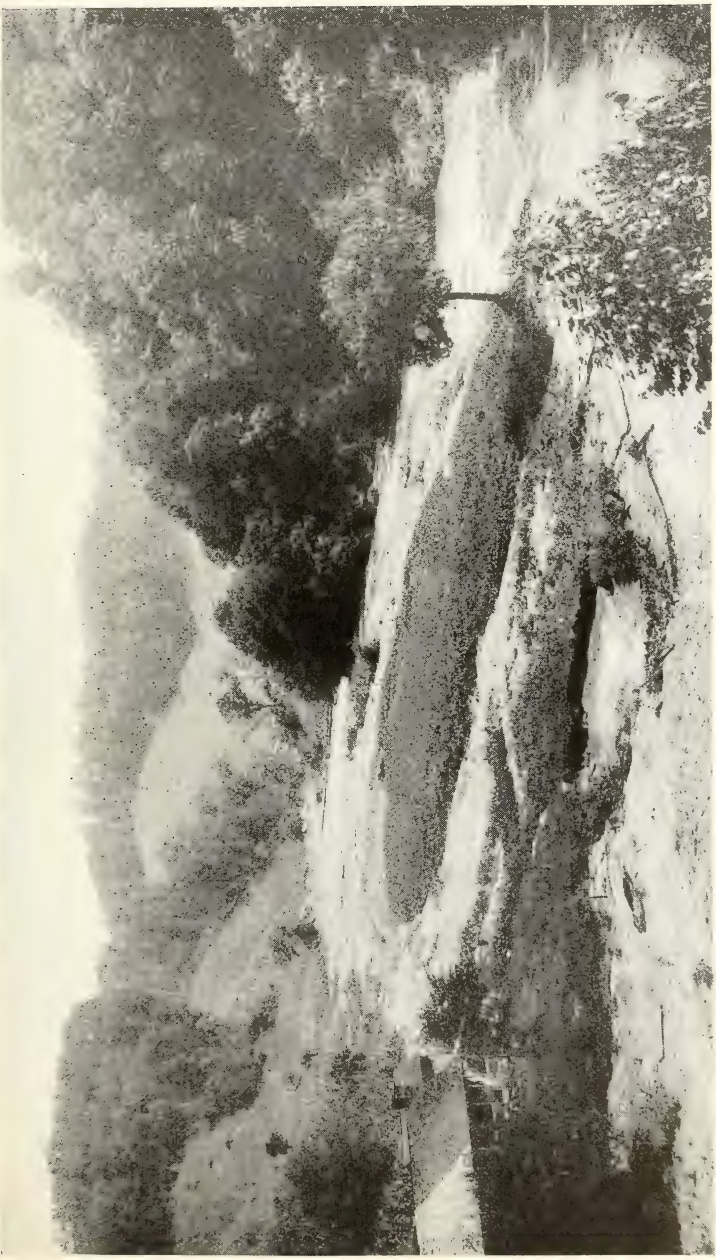
These conditions of soil and climate, which are so unfavorable for equable stream flow, attain their maximum on the lower reaches of the most southern streams, the Potomac and James. Here the rainfall is heaviest and most irregular, the protective humus is thinnest, and the heavy clay soils of the Piedmont Plateau, naturally deficient in granulation and absorptive capacity, replace the more permeable though shallow sands and loams of the upper portions of their basins, where the conditions are more nearly like those determining the clearness of New England streams.

RIVER SYSTEM OF THE SOUTHERN APPALACHIANS

The southern Appalachian group includes a very large number of rivers the flow of which is characterized by high floods at irregular intervals, usually highest in the spring, followed by long intervening periods of low water.

This river system embraces the greatest number of navigable rivers in the United States and has the greatest mileage of navigable waters, although at the present the rivers are very little used in comparison with the actual possibilities. The total power resources, minimum flow, are placed by the Geological Survey at 3,340,000 horsepower.

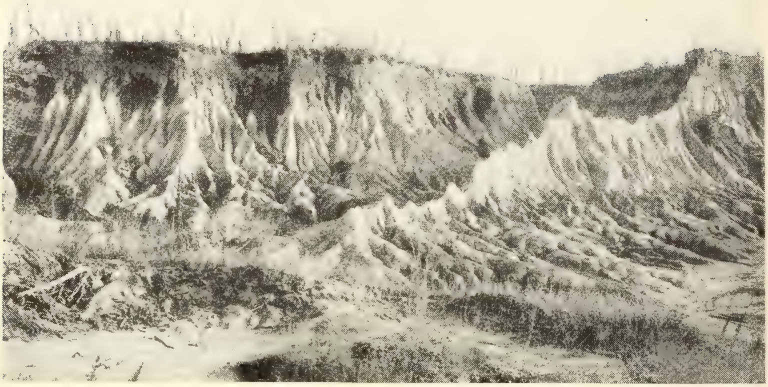
On the southern Atlantic drainage the Roanoke, the Neuse, the Cape Fear, the Peedee, the Santee, the Savannah, and the Altamaha Rivers are all important streams. With these can be included the White River and other streams of the Ozark region. On the Gulf drainage the Apalachicola, the Black Warrior, and the Mobile River systems embrace many hundred miles of navigable waters and traverse the coal fields of Alabama. The Tennessee, the Cumberland, and the Kentucky River basins cover the entire State of Tennessee and portions of other States. (Pl. 14, figs. 1 and 2.) The rivers have their sources in the southern Appalachian Mountains or in the adjacent plateau regions. In the lower portion of the Mississippi



F25375

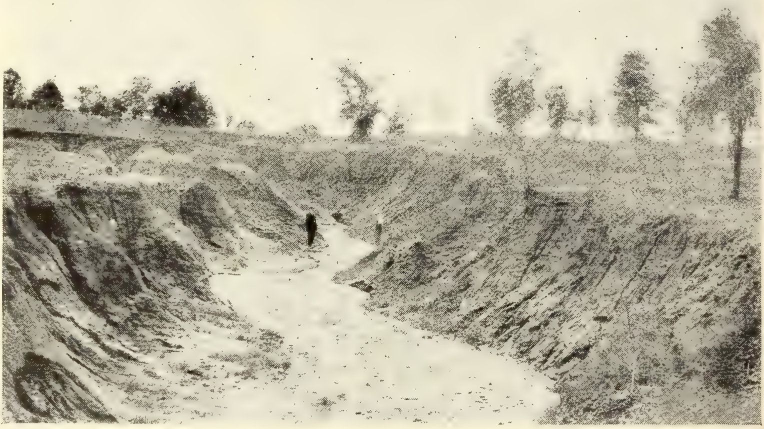
CORRASION OF BANKS AND MEANDERING STREAMS

This frequently follows land greed, and results from cutting of all trees and shrubs along the streams' banks and cultivation to the very water's edge. The consequence in this case and in many others is that all alluvial land is destroyed



F39330A

FIG. 1.—Once a part of a farm. Corn can be seen on the land still in cultivation. Fayette County, Tenn.

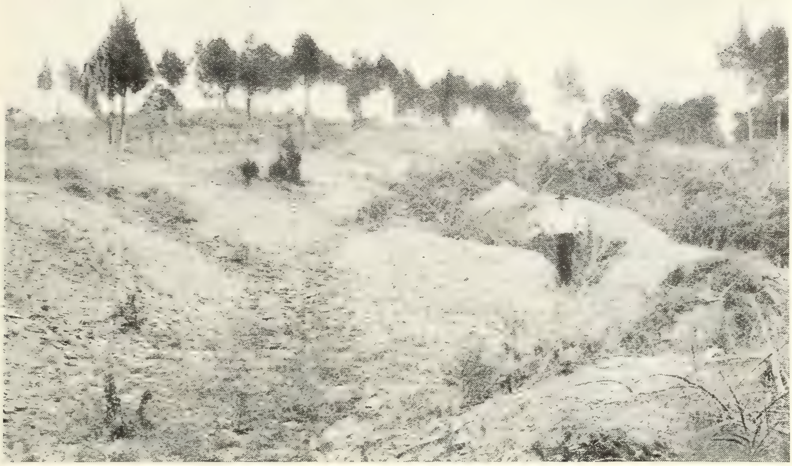


F39321A

FIG. 2.—A strip from this field has had free transportation down the Tennessee River. Carroll County, Tenn.

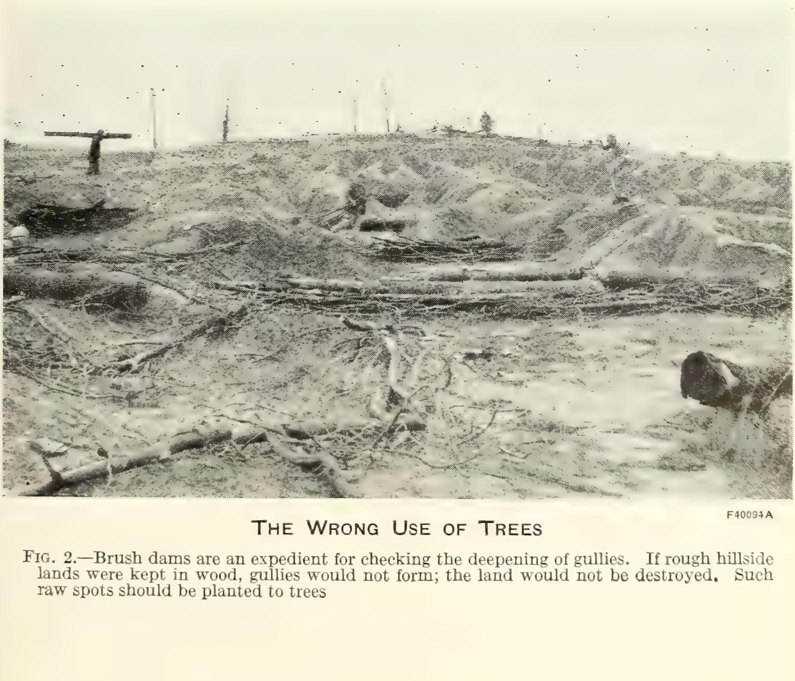
EROSION OF FARM LAND

The yearly burden of the Tennessee River is 11,000,000 tons of soil, in large part from lands such as these. The Army engineers' report on the Tennessee River notes the extensive deposits of silt in the reservoir at Muscle Shoals already materially reducing its pondage



OPPORTUNITY FOR PLANTING TREES

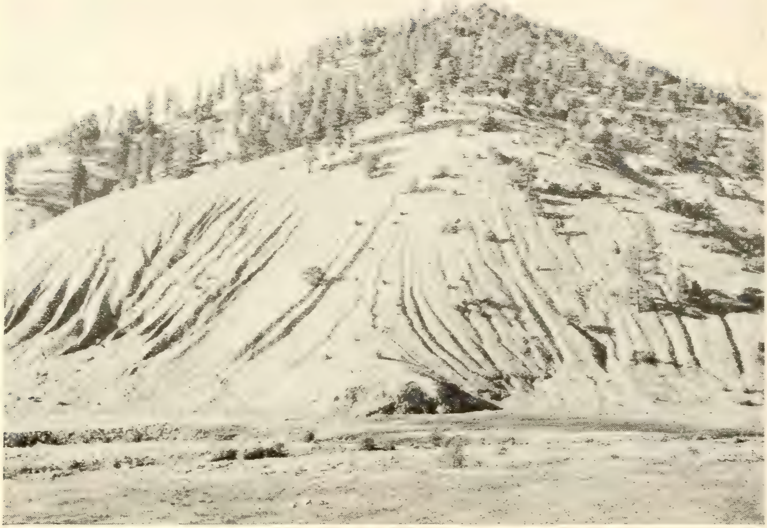
FIG. 1.—Employing brush in gullies to hold earth washed from slopes above the gullies. Planting trees is permanently more effective



F40094A

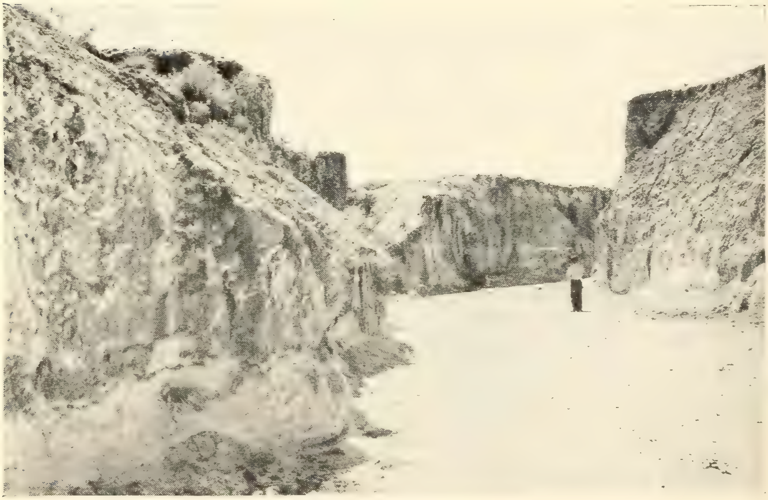
THE WRONG USE OF TREES

FIG. 2.—Brush dams are an expedient for checking the deepening of gullies. If rough hillside lands were kept in wood, gullies would not form; the land would not be destroyed. Such raw spots should be planted to trees



PECOS RIVER. (TRIBUTARY OF RIO GRANDE)

FIG. 1.—Erosion following removal of timber cover and as a result of excessive grazing. Santa Fe Creek, N. Mex. Typical of the headwater region of the Rio Grande and the southern tributaries of the Colorado River



ARKANSAS RIVER

FIG. 2.—Erosion in dry gulch tributary to Fountain Creek, near Pueblo, Colo. Erosion of this kind is not an infrequent sequence of heavy rains in this region of unconsolidated soils which lack the protective cover of vegetation. Many similar arroyos can be found on the Pecos River, Rio Grande, and tributaries of the Colorado River in New Mexico

Valley there are a few streams subject to nearly the same influences, such as the Pearl River of Mississippi, which may appropriately be included.

Fifty-seven of the Appalachian streams have 9,241.5 miles of navigable water. Most of them are navigable many miles above the tidal limit. The power which can be developed from these rivers is in many instances as important as their use for navigation, especially in those regions which are remote from coal mines.

The most typical streams rise at high elevations, 3,000 to 5,000 feet, in the Appalachian Mountains where they are fed by many swift tributaries. Leaving the mountains, they flow less rapidly through the hill country of the Piedmont Plateau or the rolling farm region of the Mississippi Valley. There is an entire absence of lakes and natural reservoirs. The forest at present covers about one-third of the area of the different watersheds.

Except in the most rugged mountains, the soil mantle over the greater portion of this region is prevailing deep—in many sections from 20 to 50 feet. The soils may be separated into three classes: (1) Loams and sands which are fairly permeable and have high storage capacity; (2) silts which are less permeable and have a lower storage capacity, and which, on account of their friability, are subject when exposed to most destructive erosion (pl. 14, fig. 1); (3) compact clays deficient in granulation which have an extremely low absorptive power and a low storage capacity and which erode badly but seldomly destructively.

The lighter soils are the most extensive in mountains and are the sources of the steadiest perennial springs. The heavy clays are extensively distributed and cover thousands of square miles on the Piedmont Plateau.

The unfavorable effect of the prevailing close-textured soils upon stream flow is further increased by the conditions governing precipitation. The snowfall is light, except in the high mountains, and the annual precipitation of 45 to 60 and even 80 inches in some localities frequently falls in concentrated showers. At several places as much as 9 inches is recorded as falling in 24 hours and at one place 22 inches within two days. Such torrential rains are destructive to steep slopes which are not protected either by a well-matted sod or by forest.

Below the mountains the humus, both in forest and in farming soil, is generally deficient, the deficiency being greatest farthest south. This lack of humus is partly due to the climate and soil, which favor the rapid oxidation of humus and partly to fires and grazing, which cause its depletion in the forest. The climate is mild, the winters are short and frequently open, and the ground is not covered by snow. The summers are long, the humidity is often high, and the rainfall is irregular and concentrated. These conditions retard the formation of humus and favor its rapid destruction.

The proportion of cleared land on the watersheds is apparently not excessive, but the condition and situation of much of it tend to jeopard not only the value of the rivers but the permanency of the soil as well. Unfavorable soil conditions have become far more general since 1880. The cultivation of extensive areas of hill country below the mountains, especially of the red clays in the extreme

South, ceased between 1880 and 1900. The rural population moved to the factory towns; the negro labor migrated to cities. Many counties in the southern Piedmont region showed a decrease in rural population during these decades, and in many there was a decrease in the total population. The surface of the farm land abandoned in this manner was quickly hardened and lost its porousness. Only a small amount of the heavy rains is absorbed by it, and much water that should be absorbed runs off, augmenting the floods; while the springs formerly fed from the water stored in the soil have failed. The land itself has eroded in deep gullies. (Pl. 15, figs, 1 and 2.) More recently, in the decade 1910 to 1920, there has been a general decline in rural population throughout the entire United States. During this decade 38 per cent of all the counties in 16 Southern States, all of them agricultural counties, lost population. In North Carolina, this loss in rural population was accompanied by a decrease of 1,500,000 acres in the area of cultivated land. But the loss in agricultural population and the accompanying shrinkage in the area of land in cultivation is by no means confined to the Southern States. It is a serious problem in every section. Much of the land, thus abandoned has been subject to destructive erosion of soil.

The irregularity and concentration of the precipitation, associated with other unfavorable conditions, frequently produce high floods, particularly on such streams as the Cape Fear and the Neuse Rivers which have narrow channels, not only in winter and early spring, when warm rains release the stored waters of snow and ice, but during the summer and occasionally in the fall as well. In these violent floods the rise of water at the fall line of the rivers frequently amounts to from 30 to 60 feet, the narrow channel having, however, an important influence upon the height of flood crest. On the other hand, during periods of drought, which occasionally extend to 60 and 90 days, that of the summer of 1925 being of more than usual severity, and the deficiency in ground water having been carried forward into 1926, the stream flow decreases until the water in the channels is very shallow. Rises of 60 or more feet above low water are known to take place in the Cape Fear, the Alabama, the Cumberland, and the Ohio, as well as in other streams.

RIVERS OF THE EASTERN SLOPE OF THE ROCKY MOUNTAINS

Rivers of the group draining the eastern slope of the Rockies embrace many streams of great length flowing east and south through the Plains. The most important are the Missouri, the Yellowstone, the Canadian, the Platte, and the Arkansas Rivers and the Rio Grande.

These streams have an erratic flow. There is a period of high water in the late spring or early summer resulting from the melting of the accumulated snows of winter, folowed by a long period of extremely low water, with very high floods at irregular intervals. Many of them, however, are extremely valuable as sources of power and for irrigation, since it is probable that a large portion of the region in which dry farming has failed may eventually be made highly productive through irrigation. After the early summer floods the autumn stages of these rivers are usually low, while the high winds and temperatures of the Plains result in high evaporation, which reduces still further the run-off of the Plains. The rainfall on the Plains, 10 to 30 inches, consists chiefly of summer precipitation, which augments the flow from the mountain sources for a short time, but in autumn becomes insignificant. Most of their upper basins are naked or sparsely timbered with open stands devoid of humus, except at the headwaters where the forested areas are small compared with the extensive unforested areas below. (Pl. 16, figs. 1 and 2.) The mountain streams which feed these rivers are of low turbidity, being fed by springs and the melting of snow on the north slopes and the higher peaks. The snow waters are reinforced by the midsummer rains of the Plains which are heaviest in June.

It is from the treeless Plains that these streams obtain the greatest portion of the silt burden. The silt burden is so excessive that many of the rivers have meandering channels from the deposit of sediment which may be in transit for only relatively short distances before being deposited. In addition to the violent fluctuations between the maximum flow and minimum dry-season flow, the constant washing of banks and formation of silt bars in the shifting channels are serious problems. The material of these silt bars is largely deposited during the spring freshets, being carried in part from the banks of the smaller tributaries of the Plains and from the unconsolidated sands and silts which constitute the prevailing soils of the Plains; to a less extent it is material brought down in flood by the mountain streams.

The silt burden in these streams is among the highest in the United States. The Missouri above Ruegg, St. Louis County, Mo., with a drainage area of 528,700 square miles, has a yearly silt burden of more than 176,000,000 tons. The Arkansas above Little Rock, with a basin of 148,000 square miles, discharges more than 40,000,000 tons of earth. The maintenance of forest cover on the mountain slopes at the headwaters of these streams is essential. It is the mountain springs which largely maintain the late autumn run-off after the melting of the snows.

STREAMS OF THE GREAT PLAINS

The streams of the Plains include the Washita, the Cimarron, the Red, the Smoky Hill, the Republican, and the Kansas Rivers. So erratic is the flow, that the Smoky Hill River, one of the chief tributaries of the Kansas, with a drainage area of 8,000 square miles, has a minimum discharge during the low-flow season of only 10 cubic feet per second. A comparison of this with a typical eastern stream—the Potomac River at Point of Rocks, Md., where the basin has a drainage area of 9,000 square miles—shows that the minimum flow of the Potomac, which for a 12-year period is recorded as 990 cubic feet per second, is ninety-nine times as great as that of the headwaters of the Smoky Hill River. The headwaters of the Arkansas, which rise in the mountains of Colorado, show a much more steady flow than those of the Kansas. At Canon City, Colo., the Arkansas drains a basis of 3,000 square miles and has a minimum flow of 108 cubic feet per second, or a flow thirty times as great as that of the Kansas River.

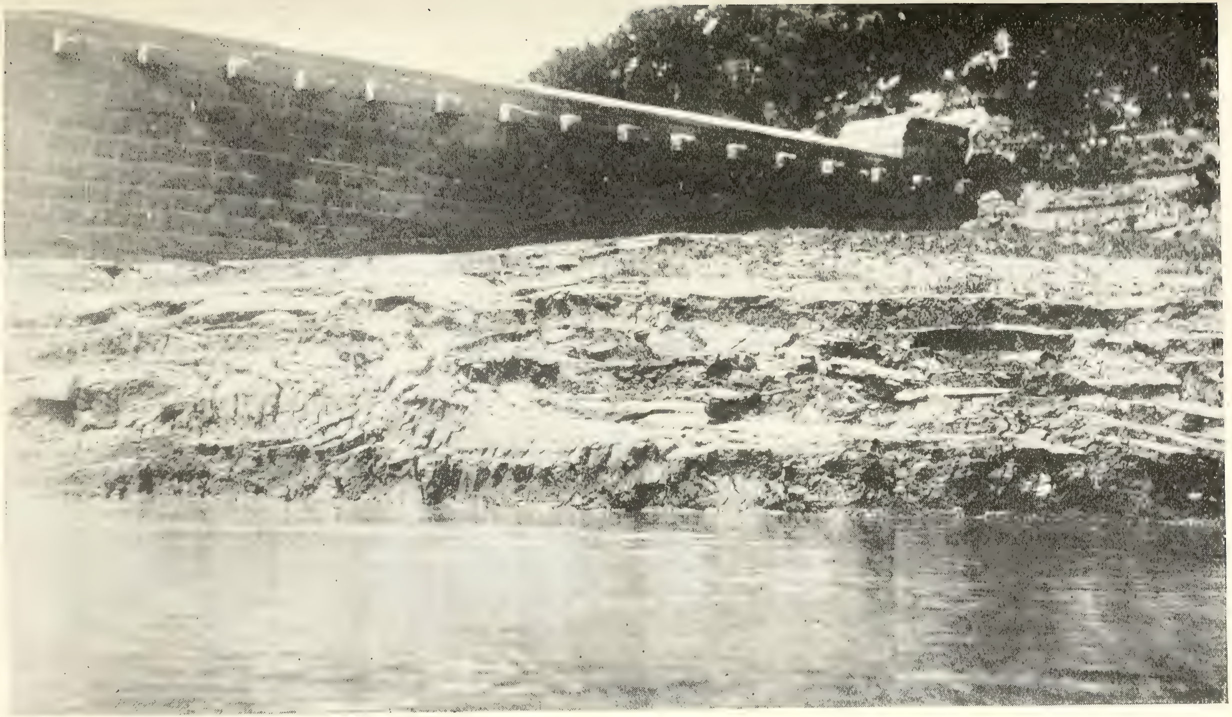
STREAMS OF THE PLATEAU OF CENTRAL TEXAS

A number of rivers of Texas have their headwaters in the deeply fissured limestones of the Edwards Plateau region of the central part of the State. These streams are normally clear. They carry, however, during periods of flood, an enormous quantity of silt eroded from the gorges and channels of the small streams which indent and canyon through the plateau region. None of these streams heading on the Edwards Plateau are fed by melting snows. They are subject to wide fluctuations between minimum and maximum flow. The floods at San Antonio and at Cameron, Tex., on September 9 and 10, 1921, are extreme examples of the maximum flow of streams of this character. At Cameron the Little River increased from a normal low flow of 177 second-feet to a maximum discharge of 647,000 second-feet. The Colorado River, on which was erected the ill-fated dam at Austin, is another. At the time this dam broke, after 10 years of service, it was found that its storage capacity had been reduced 56 per cent during the decade as a result of siltings. T. U. Taylor reports that the new reservoir, constructed in 1913, had lost 84 per cent of its capacity through silting by 1922. (Pl. 17.) The silt burden of the Colorado River (of Texas) is roughly estimated at 1 per cent of its volume or an average of 18,000 acre-feet a year. The Weather Bureau records show a rainfall of 0.9 of an inch within five minutes at Taylor and 4.46 inches in one hour at Palestine. Only a small portion of rains of such intensity can be absorbed, since if there is any colloidal content in the soil the surface quickly puddles and further absorption takes place slowly.[18] The Brazos River above Waco, with a drainage area of 30,000 square miles, bears more than 3,200,000 tons of soil a year.

The streams of this region, notwithstanding their high silt burdens and the possibility of poor foundations on which to erect dams on certain sites, present many excellent opportunities for water storage in their deep canyons, which in places spread out into broad basins; and nowhere would the results from water storage be of more benefit. Not only might storage result in preventing, or at least in lessening, the ravages of such floods as that which visited San Antonio, but it would furnish a great deal of power and water for irrigation in a section which is subject to long and costly droughts. It might be possible through such storage to irrigate a considerable portion of the Edwards Plateau region and thus add enormously to the value of these lands, the utility of which at present is largely restricted to grazing and that itself sometimes uncertain as during the drought of 1924. It would probably be necessary to make provision for flushing the silt from reservoirs by means of water stored in smaller reservoirs located above and constructed with this object in view, if this procedure should prove feasible. The woodland and herbaceous cover of this region is too light, on account of the limited rainfall, to protect the surface from erosion, but it is possible by adequate regulation of grazing, and by better protection of stream banks if not to reduce erosion at least to prevent its further increase. Range depletion as well as the maintenance of the protection of the cedar brakes requires careful investigation.

---

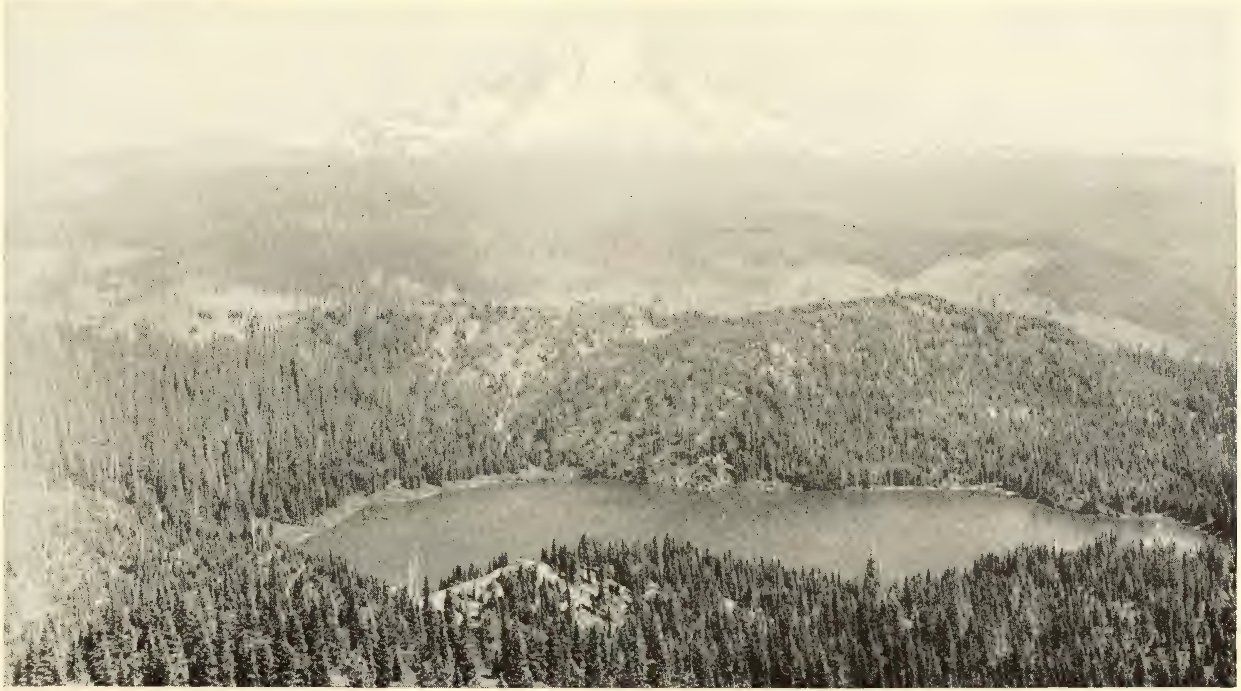
[18] See footnote 12 on p. 7.



F24898

REMNANT OF SILT BED ABOVE DAM ON COLORADO RIVER AT AUSTIN, TEX.

The pondage of the reservoir was nearly destroyed after 10 years' service. The dam broke and a large portion of the silt was washed away. The silt burden of the Colorado River sometimes exceeds 5 per cent



FOREST INFLUENCES LOW, COLUMBIA RIVER WATERSHED

The snow fields of Mount Adams and Council Lake in foreground as feeders of Lewis River. Extensive areas of heavy forest protect the soil and limit erosion. The pale areas within the forest are burns

COLORADO RIVER AND GREAT BASIN

Two fundamentally different conditions are exemplified in the streams which drain the Colorado River basin. One condition is represented at the headwaters of the northern streams, the other in all the remaining portions of the basin.

The headwaters of the northern streams, in southwestern Wyoming and in Colorado, have their sources within the forested mountain slopes. They are partly fed by melting snows and are largely clear until they enter the Plains. The precipitation in the mountains, much of it in the form of snow, varies from 16 to 40 inches a year; on the Plains the yearly average rarely rises above 15 inches, being lowest in summer and highest between December and April.

The soils of the Plains are of many origins and vary in character but are prevailingly unconsolidated. The rainfall is too scant to support more than a growth of brush and chaparral or in places open woodland. The flood seasons of the northern streams are in the spring, in June, and in the fall. The spring and fall floods are due to rain, partly on the Plains; but the June floods, which are the highest, come from melting snows in the mountains. The early spring and autumn floods which result from rains, especially on the Plains with their scanty protection of vegetative cover, produce the greatest turbidity. The June floods, which are the highest, are not marked apparently by increase in silt burden. The rather limited record at Topock shows a stream of "only normal irregularity" approaching even the Columbia in evenness of flow. The relation of minimum run-off (January 4, 1925) to maximum (June 22, 1921) is as 1 to 92.

Forests are important in protecting these mountain head streams, in holding snow banks, in shading them and in retarding their melting. The absence of forests or even of adequate soil cover on the Plains, where the rainfall is insufficient to support such a growth, accounts for the high silt burden acquired by these streams in their passage through the Plains notwithstanding the prevailingly gentle topography.

The streams of the Great Basin and the southern tributaries of the Colorado River beginning with the San Juan have their sources either within the Plains or in low mountain ranges in Arizona, New Mexico, southern Colorado, Utah, and Nevada. Not only is the total precipitation which feeds these streams less, rarely rising above 20 inches and then only along the higher mountains, and with an average rainfall as low as 10 inches over much of the Plains and desert country, but very little of it is in the form of snow. Summer rains are the rule. Violent thunderstorms occur frequently, accompanied generally by high winds and sometimes by very concentrated precipitation. Great clouds of dust are usually carried by the wind in front of the storm. These heavy rains may alternate with long periods of drought. The Plains consequently have a scant vegetation of brush or chaparral and the areas of lowest rainfall are deserts with cactus as characteristic shrubby vegetation and very little grass cover. High temperatures over the lower-lying lands make a high evaporation factor and add to the irregularity of the run-off resulting from the sometimes concentrated rainfall. The Virgin River, which is a characteristic stream of this group, though "rising at an altitude of about 8,000 feet, soon drops into a sandy valley where it becomes a river of flowing sand. In ordinary stages it is very wide but very shallow rippling over the sand in tawny waves." Only an insignificant portion of the basins of these streams is really forested, so little that forests play a negligible rôle in affecting their regimen, which is determined by the heavy, irregular rains, the unconsolidated soils through which they flow, and the high summer temperature on the Plains.

At Yuma, below all of the important tributaries, the silt content of the Colorado River is estimated to average 7,000 parts per million and the total solid burden to amount yearly to 160,000,000 tons, of which less than 10,000,000 tons comes from the northern sources covering one-half of the basin and furnishing three-fourths of the discharge. Since the silt content is diluted by the smaller solid burden and larger volume of the northern sources " it shows that the lower Colorado River derives most of its enormous load of silt from the drainage area which includes the San Juan, the Paria, the Little Colorado, the Virgin, and the Gila Rivers," and that this silt comes from the region of unconsolidated soils with the scant cover of vegetation, limited precipitation consisting largely of rain which often falls in heavy showers. A rain of about 4 inches on September 17 and 18, 1923, over a portion of the basin of the Little Colorado caused an increase in discharge of the main Colorado from a normal of 10,000 feet per second to 110,000 feet per second. Except in the low mountains, which are only in part forest covered, the rainfall is too scant to support any general vegetative ground cover sufficiently dense to afford protection to the soil. Consequently erosion is active even where the rainfall is slight.

The potential horsepower of the Colorado River has been placed at 7,000,000, to be secured largely through the employment of 13 power sites and storage reservoirs on the main stream and the mountain-fed tributaries. The proposed Boulder Canyon Dam, at which the largest development would be obtained, would be 600 feet high and would impound 32,000,000 acre-feet of water, developing about 600,000 constant horsepower and 1,500,000 horsepower three-fourths of the time. The water, heavily laden with silt, would be desilted by sedimentation in the reservoir. (See footnote 11, p. 6.) Much of the water used for power purposes would also be available for irrigation, and the city of Los Angeles plans to use the desilted water as a source of municipal supply. It is estimated that the storage capacity of this reservoir would as a result of silting be largely destroyed within 150 years. Since the silt burden of the river at this point is often more than 2 per cent, the rate of shrinkage in storage capacity will probably be far more rapid than indicated by this estimate.

STREAMS OF THE SACRAMENTO AND SAN JOAQUIN BASINS

The streams of the Sacramento and San Joaquin Basins are subject to violent early spring freshets, originating in the heavy rains in the mountains; and their high silt burden has damaged the navigable estuary channels. The greater portion of the silt of these streams was formerly the result of hydraulic mining and even now much silt is derived from old tailings which are still in transit. California, like Colorado, has laws prohibiting contaminating streams with tailings and the necessary means have been taken to control this through settling beds. In spite of this control measure, however, the Sacramento River bears annually more than 2,250,000 tons of solid burden. Much of this is acquired in the foothills and plains, though considerable erosion takes place in the higher mountains and on the deforested region above Redding. Except at high altitudes much of the forest land has insufficient humus beneath the comparatively open stands of trees and there is within the forest a general absence of dense brush or of grass and of other herbaceous cover. This condition is far more prevalent in the mountains of the southern portion of the State than to the northward and at lower altitude than at higher. The rainfall even in the mountains toward the south is insufficient to support forests, the cover of the San Bernardino and other mountains in this section being largely open stands of brush. (Pl. 7.) Corrasion is active on the Tuolumne, the Stanislaus, and other streams of the Sierras which debouch into the Sacramento or the San Joaquin Rivers. This washing of stream banks is more or less constant, being a characteristic of streams coursing through unconsolidated soils or those deficient in cohesion, as are many of those of the California Basin. On the smallest tributaries this action might be lessened by protective planting.

Violent irregularities in the character of the precipitation, especially in the southern Sierras, add to the degrading influence of the streams, and make the lessening of erosion an important consideration. Although the general rainfall of California is light, 12 to 35 inches, one-half of it normally falls during three months—December, January, and February. In years of maximum precipitation the rainfall during this three-months' period will often equal or exceed that which would fall in the South Atlantic States during the same time. The rainfall of lower altitudes is frequently concentrated, and this is especially favorable for erosion. Only at the higher elevations is a large part of it snow, and its melting is often forced by a warm rain. The snow fields are found only at the highest altitudes,and even on Mount Shasta and Mount Whitney, although they do much toward sustaining stream flow during the dry season, they are not perennial, and except in gulches and north slope canyons, largely disappear after midsummer.

The functions of forest cover in limiting erosion are at an optimum at middle and lower altitudes in the Sierras of middle and southern California because of the character of the rainfall, which while sufficient to maintain a forest cover is irregular and frequently so concentrated that destructive erosion takes place wherever the soil is not adequately protected by a blanket of humus. South of the higher mountains and in the foothills, the lower rainfall and high evaporation factor preclude forest growth, or at best permit only the growth of thin, open stands of woodland with humus, so scant that it is rapidly dissipated through nitrification and there is a general absence of dense herbaceous and shrubby ground cover. In case the humus is destroyed grass does not form a sod. On the northern coast of California the conditions partake of those on the Columbia

River drainage, which are a heavier rainfall but more regularly distributed and not so concentrated and a lower evaporation factor. These are conditions which insure the formation of a dense sod wherever the humus cover is broken and there is sufficient light. Erosion consequently is not nearly so active in this region as in those portions of California where the rainfall is more irregular and where sod and dense herbaceous ground cover do not generally set on naked soil.

COLUMBIA RIVER AND THE EXTREME NORTHWEST

The precipitation near the northwest coast, which is the heaviest in the United States, reaches the maximum on the west slope of the Coast Range Mountains and chiefly affects small streams which drain directly into the ocean. Many of these are subject to high floods, especially during the winter and early spring, the seasons of heaviest precipitation. Notwithstanding the prevailingly porous and granular soils, a soil cover is necessary to prevent excessive erosion. When the timber is removed, most of these soils naturally set to sod and brush, but where this is not the case the protection afforded by forest cover with its prevailingly excellent humus is necessary to prevent erosion on the steeper mountain slopes. Notwithstanding the difference in the seasonal distribution of rainfall, the conditions closely resemble those of many of the tributaries of the Tennessee River which flow from the Smoky Mountains.

This, however, is not the case with the Columbia River, the salient feature of which is its clearness and the relative evenness of its flow, notwithstanding flood crests of 60 feet above low water. The streams which most closely resemble it in the United States are those of New England, but the flow of the Columbia is probably more uniform than that of any other large stream of the United States unless largely fed from lake storage. This condition is due to several causes: the prevailingly light character of the precipitation, especially over the Plains region where the soils are largely unconsolidated and to the covering of vegetation, largely brush and grass even on the plains; the granular character of the soils in the mountains; the large proportion of the run-off which comes from snow fields and glaciers and which takes place during midsummer, thus supplementing the run-off from rainfall which largely takes place during winter and spring, and which is rarely so concentrated as over the southern portion of the Great Basin, over the southern part of the Great Plains, and in New Mexico and Texas. There is also some lake storage on the Canadian drainage.

The heavy rainfall of the coast decreases on the eastern slopes of the Cascades and in the Plains areas is less than 15 inches, rising as the Rocky Mountains are approached to 20 inches and attaining in the mountains of northern Idaho and on the headwaters of the Clark Fork a maximum of 35 inches, and on the headwaters of the Lewis Fork a maximum of 30 inches. This precipitation is relatively slight, and it is of a character to render it available for soil absorption; also the prevailing surface conditions are highly favorable. The precipitation during the summer is extremely low compared with that during the winter, but is largely in the form of gentle showers, giving fullest opportunity for entire absorption with a very small amount of surface run-off. The winter snowfall is heavy, especially in the eastern mountains; and the deep snow banks in gulches and north hollows and where protected by the dense forest of conifers from sun and wind melt gradually during spring and summer, maintaining a steady stream flow. This not only compensates for the deficiency of the summer rains, but the absence of such rains is favorable, since they would accelerate the melting of the snow. The snow drifts and fields of the high peaks of the Cabinet, Coeur d'Alene, and Bitter Root Mountains, and of the Continental Divide sometimes last until reinforced by those of the succeeding winter. In the Williamette the snow-water flow is uninterrupted, for it is largely fed by the glaciers and perpetual snow fields of Mount Hood and Mount Jefferson, just as Lewis River is fed from the snow fields of Mount Adams. (Pl. 18.)

The torrential spring flood of the Northeastern States from the warm spring rains on the winter's snow, and the high, early summer flow of the streams of the Southwest from the rapid melting of the mountain snow under the high temperature of early summer, are both much reduced on the Columbia. The freshet season extends from May to July. The melting of snow in the mountains of Idaho and Montana is usually a gradual process, frequently occupying the entire summer. Rarely there may be accumulated snow in the forests and a late spring followed by very warm rains producing high floods such as those of 1826, 1854, and 1894. The northern tributaries are less erratic in their flow than the southern, and several lakes add to their stability of flow. Occasionally, however, a warm chinook wind will melt much of the snow during April, or even in March, causing high turbidity and floods on streams like the Clearwater and Lewis Fork. These winds, however, are exceptional and usually of short duration. The flood season, when the streams are very muddy, is usually two months later. The extension of cultivation has had little effect in increasing turbidity, since the cultivated lands are largely in the more level valleys and on account of the character of the precipitation.

Although the equable flow of these streams is primarily a result of the climatic conditions, the influence of the mountain forests is serviceable in protecting the snow from evaporation and lessening the rapidity of its melting. It is of greater value in checking erosion, notwithstanding the prevailing porous soils of the mountains, while the large amount of brush beneath the timber and the readiness with which grass, other herbage, and shrubs come in on naked soil are important factors.

On the Plains the rainfall is of such character, both in distribution and amount, that there is scant erosion. Although the silts of the Priest, the Pend Oreille, and other agricultural river valleys of the eastern headwaters of the Columbia are incoherent, the limited rainfall precludes the possibility of excessive erosion, unless at times of concentrated precipitation, a character of rainfall to which this region is seldom subjected. Should erosion of these soils take place, however, the placid portion of the Pend Oreille and other streams offer suitable situations for silting.

SUMMARY OF REGIONAL CONDITIONS

In the Northeast, in the region of the Great Lakes, and on the Columbia River, the silt burden of streams is on the whole negligible. There are no marked periods of extremely low water, disastrous floods are infrequent, and there is a low ratio of minimum to maximum flowage. The forest cover exercises little influence in determining the life of reservoirs.

The streams of the Middle Atlantic States, in spite of a wide margin between maximum and minimum discharge, have a much lower turbidity than those farther south. The drainage basins of many of them, however, are on sandy, shaley, or very permeable soils, especially at their headwaters, and for this reason erosion of soil proceeds at a comparatively slow rate even on denuded sites. Forests exercise a considerable protective function.

The streams of the Great Plains, and likewise the western Colorado River, flow through vast areas of unconsolidated soils on which, because of irregular and deficient rainfall, it is not possible in many places to maintain vegetative cover of sufficient density to obtain protection against erosion. Forest cover, however, exercises a high influence upon the headwaters of such of these streams as lie within the forested portions of the Rocky Mountains. The streams which have their headwaters in central Texas are in the same general class as those of the Great Plains. The rainfall, however, is more irregular, at times torrential, followed by long periods of scant precipitation. A consequence of this is extremely erratic flow of the rivers. The basins of these streams are largely covered with open parklike stands of trees, and there is a fairly good cover of grass, which in this region forms a more efficient protection than the scattered trees. A few areas of real forest occur, however, chiefly on the low mountains, and they should be carefully protected. On the whole, however, the protection afforded by forest cover is inconsequential.

It is in the Appalachian and adjacent Piedmont regions from Ohio and Maryland to northern Mississippi, and in the similar Ozark region of Missouri and Arkansas, in the mountains of middle and southern California, and on the slopes of the Rocky Mountains south of middle Colorado that forests seem to exercise their maximum influence in the protection of reservoirs. In these regions rainfall is irregular and often concentrated; soil where denuded erodes easily, contributing a high solid burden to streams; snowfall is light; and there is little lake storage. When forests are reestablished on such denuded lands, and reestablishment is readily effected, erosion of soil is largely checked.

Table 1 shows, for typical streams in different hydrographic regions of the United States, the comparative amount of turbidity, relation between maximum and minimum flow, and precipitation on the basin of the stream with maximum rainfall for each region.

TABLE 1.—*Flow and turbidity of typical streams of different sections of the United States*

	Area basin	Suspended matter	Average annual precipitation on basin [2]	Maximum rainfall for region [2]		Flow: Second-feet per square mile of drainage areas		Relation minimum to maximum flow
				Per day	Per month	Maximum	Minimum	
	Square miles	*Parts per million* [1]	*Inches*	*Inches*	*Inches*			
Northeast and Lakes regions: Connecticut	3,100	--------	42	8.31	17.55	18.5	[3]0.09	1 to 205
Middle Atlantic: Susquehanna	24,100	21	45	8.37	15.82	29.0	.09	1 to 322
Southeast: Savannah	7,294	142	62	22.22	35.49	42.5	.19	1 to 233
Texas Plateau: Colorado (of Texas)	34,200	351	32.5	23.98	25.87	7.0	.0003	1 to 18,000
Rocky Mountain, east slope: Missouri above Fort Benton	24,600	--------	24	--------	6.90	2.2	.09	1 to 24
Plains: Kansas at Lecompton	58,600	2,032	25	10.33	18.67	3.1	.0011	1 to 2,820
California: Sacramento	257	81	[4] 78	9.68	71.54	62.0	.43	1 to 145
Northwest: Columbia	237,000	[5] 40	45	7.66	20.14	5.0	[7].18	1 to 28
Interior Basin: Colorado:								
Colorado (Grand) [6]	26,200	720	26	--------	--------	4.6	.02	1 to 230
Gila at Yuma	71,000	5,000	16	--------	--------	[8] 2.8	[9].00	--------

Connecticut, above Orford, N. H. (1904–1923): Maximum, March, 1913; minimum, September 28, 1908.

Susquehanna, above Harrisburg, Pa. (1889–1920): Maximum, June 2, 1889; minimum, September 28–29, 1900.

Savannah, above Augusta, Ga. (1884–1891): Maximum, 1888; minimum, October 16, 1904.[10]

Colorado, above Austin, Tex. (1898–1923): Maximum, April, 1900; minimum, August, 1918.[11]

Kansas, above Lecompton, Kans. (1899–1906): Maximum, May 31, 1903; minimum, March 6, 1902.[12]

Although the conditions of the Kansas at Lecompton are so unfavorable, on the headwaters of the Missouri River at Fort Benton, drainage area 24,600 square miles, the conditions are as follows: Maximum flow, 2.2 second-feet; minimum flow, 0.09 second-foot; relation, 1 to 24.[13]

Sacramento, above Castella, Calif. (1910–1920): Maximum, January 2, 1914; minimum, August 5 to September 21, 1920.[14] This is the fork of the Sacramento River which heads in the mountains.

Columbia, above The Dalles, Oreg. (1879–1919): Maximum, 1894; minimum, January, 1890.[15]

[1] U. S. Geological Survey.

[2] U. S. Weather Bureau.

[3] This low minimum evidently the result of artificial storage on preceding day.

[4] The rainfall given is that at Helen mine, the heaviest in the basin. The average rainfall for the basin is 23 inches.

[5] The material comes largely from the Idaho plains, which are treeless.

[6] For Grand, Green, and Gunnison above junction, since only scant figures are available for any one stream.

[7] 1925.

[8] June 22, 1916. This was chiefly from the Salt River, but no records on that stream.

[9] Dry for one or more months each year.

[10] NEWELL, F. H. RESULTS OF STREAM MEASUREMENTS. U. S. Geol. Survey Ann. Rpt. (1892–93) 14 (2): 148. 1894.

[11] GROVER, N. C., GRAY, G. A., and ELLSWORTH, C. E. SURFACE WATER SUPPLY OF THE UNITED STATES, 1918. PART VIII. WESTERN GULF OF MEXICO BASINS. U. S. Geol. Survey Water-Supply Paper 478: 29. 1922.

[12] KANSAS WATER COMMISSION. SURFACE WATERS OF KANSAS, 1895–1919. 463 p., illus. Topeka. 1921.

[13] GROVER, N. C., LAMB, W. A., and FOLLANSBEE, R. SURFACE WATER SUPPLY OF THE UNITED STATES, 1918. PART VI. MISSOURI RIVER BASIN. U. S. Geol. Survey Water-Supply Paper 476: 17. 1921.

[14] GROVER, N. C., MCGLASHAN, H. D., and HENSHAW, F. F. SURFACE WATER SUPPLY OF THE UNITED STATES, 1919 AND 1920. PART XI. PACIFIC SLOPE BASINS IN CALIFORNIA. U. S. Geol. Survey Water-Supply Paper 511, 456 p., illus. 1923.

[15] PARKER, G. L., and LEE, L. SUMMARY OF HYDROMETRIC DATA IN WASHINGTON, 1878–1919. U. S. Geol. Survey Water-Supply Paper 492, 363 p., illus. 1923.

If the average quantities of suspended matter in the water and the wide ratios between maximum and minimum flow are used as a guide, the streams of the Plains region and those of Texas and the Southwest are more urgently in need of protection than those of any other group. The very conditions, however, which determine the wide fluctuations between maximum and minimum flow—that is, the extremely irregular rainfall and the long periods of drought broken by short periods of most concentrated precipitation (practically 24 inches having fallen in a single day in Texas, which is three-fourths of the precipitation for an average year)—make it difficult or even impossible to maintain a forest cover over those portions of the basins of these streams from which the turbidity is derived. In many places it is impossible to maintain a sufficient cover of shrubs and grasses to afford even a moderate protection against erosion of the soil.

It is significant that most of the turbidity of the streams of the Plains seems to come from below the mountains. As explained in the note to Table 1, the headwaters of the Missouri River show a most equable flowage as a mountain stream, the maximum flood flow being only 24 times the low-water flow. The regimen of the Missouri River as it emerges from the mountains is changed by the tributaries from the Plains. From these tributaries also comes the large burden of solid material which is borne by the Missouri in its lower reaches and which gives it the unenviable reputation of being one of our muddiest rivers, a stream which can well be compared to the Yellow River of China. The headwaters of streams which pass through the Plains but head within the mountains are materially benefited by protection; and all protective cover, whether of grass, brush, or forest, should be most carefully maintained.

At the other extreme from the rivers of the Plains, including those of Arizona and those of the southern portion of the Great Basin, are those of the Northeast, the Lakes region, including Wisconsin and Minnesota, and the extreme Northwest. The streams of these regions have a remarkably low turbidity and a low ratio of maximum to minimum flow. Reservoirs constructed for storage of storm water consequently have a long life. Not that protection is not desirable, even in the case of these streams, but of all our rivers, the streams of these sections most nearly approach the ideal in the eveness of their flow. The distribution of rainfall in these sections is such that there is little land which can not be protected by means of grass or forest cover.

The streams of the southern Appalachian and Piedmont region and those of California, seem to occupy an intermediate position. Normally they have moderate turbidity and have fairly even flow in comparison with the streams of the Plains and with those of Texas; but their flow is widely fluctuating when compared with the streams of the Northeast. The rainfall is periodically heavy, although sufficiently well distributed to maintain an ample forest cover for thorough protection. In the Appalachians more than 35 inches of rain have fallen within a month and in the mountains of California more than 71 inches within the same period. In both regions extremely concentrated precipitation frequently takes place, more than an inch sometimes falling within much less than an hour. The soils are such that, when they are denuded or exposed, erosion proceeds at a hight rate; but it is always possible to obtain thorough protection by forest or other cover, the forest being as a rule decidedly most efficient and preferable.

SUMMARY

On account of the wide fluctuations in the discharge of streams employed for the generation of power, especially hydroelectric developments, reservoirs are being located on their headwaters for the purpose of storing storm waters and thus equalizing the flow of the streams and obtaining a more thorough utilization of power.

If it were ascertained that the pondage of a reservoir located on a head stream was in danger of being materially reduced through erosion of soil from denuded land, it would be justifiable from an investment point of view to expend in the preservation of the storage capacity or in the extension of its life a sum of money which would not exceed the present value of the prolonged life of this storage capacity.

The acquisition of the denuded land on which erosion is most excessive and the planting of it to trees, not only offer means of greatly reducing the erosion, but promise returns from the investment so made. If such denuded lands can be acquired at a sufficiently low price, the returns from the growth of the timber may be expected to pay for the entire cost, with interest, of the land and its afforestation. Under some conditions the cost of the land and its afforestation would be so high that the growth of the timber would probably not return a current rate of interest on the investment. In such cases it would be economically desirable for the additional cost of the land and afforestation to be charged against the prolonged utility value of the reservoir. There would then be justification for expending in this way such a sum as would equal the present value of the prolonged life of the reservoir.

One of the most important considerations in determining the location of reservoirs for such a purpose is the life of the reservoir and the rate at which the initial pondage is lost through siltage due to erosion of soil.

The streams in the different parts of the United States may be grouped in relation to the quantity and irregularity of their run-off, their turbidity, and the value of forest cover in protecting their headwaters, and thus influencing the quantity of their solid burden.

In such a classification it appears that, because of the character of the soil, the rather small amount and even distribution of the precipitation, and the extensive storage of water in lakes and mountain snow fields, forests exercise a generally low influence in the Northeast, in the Lake regions and in the Northwest.

At the other extreme are the rivers of the Great Plains and Texas and the Colorado River. These streams flow through regions which, on account of the extreme irregularity and scantiness of the rainfall, are largely treeless or wooded only with scattered groves, and in consequence the influence of the forest cover is negligible.

There is an intermediate type of stream on whose watershed the forests do exercise a most important function in the protection of reservoirs. This type embraces the streams of the southern Appalachians, those of the southern Piedmont region, most of those that rise in the mountains of southern California, and the headwaters such of those as have their sources in the southern part of the Rocky Mountain system. They are within regions of irregular and usually heavy rainfall. Their headwaters at least are in forest regions. Wherever extensive areas have been denuded and exposed to concentrated rainfall, most of these streams have during floods high turbidity. If there have been no clearings on the headwaters of streams within these regions, or if the surface has not been denuded or exposed by fires, erosion is slight, there is a small quantity of solid burden, and silting threatens the capacity of storage reservoirs only to a slight degree. If there is excessive erosion due to soil exposure, it is possible to reestablish forest conditions and by doing so reduce erosion and lessen sedimentation.

ORGANIZATION OF THE UNITED STATES DEPARTMENT OF AGRICULTURE

July 29, 1926

Secretary of Agriculture	W. M. JARDINE.
Assistant Secretary	R. W. DUNLAP.
Director of Scientific Work	———
Director of Regulatory Work	WALTER G. CAMPBELL.
Director of Extension Work	C. W. WARBURTON.
Director of Information	NELSON ANTRIM CRAWFORD.
Director of Personnel and Business Administration	W. W. STOCKBERGER.
Solicitor	R. W. WILLIAMS.
Weather Bureau	CHARLES F. MARVIN, *Chief.*
Bureau of Agricultural Economics	THOMAS P. COOPER, *Chief.*
Bureau of Animal Industry	JOHN R. MOHLER, *Chief.*
Bureau of Plant Industry	WILLIAM A. TAYLOR, *Chief.*
Forest Service	W. B. GREELEY, *Chief.*
Bureau of Chemistry	C. A. BROWNE, *Chief.*
Bureau of Soils	MILTON WHITNEY, *Chief.*
Bureau of Entomology	L. O. HOWARD, *Chief.*
Bureau of Biological Survey	E. W. NELSON, *Chief.*
Bureau of Public Roads	THOMAS H. MACDONALD, *Chief.*
Bureau of Home Economics	LOUISE STANLEY, *Chief.*
Bureau of Dairying	C. W. LARSON, *Chief.*
Fixed Nitrogen Research Laboratory	F. G. COTTRELL, *Director.*
Office of Experiment Stations	E. W. ALLEN, *Chief.*
Office of Cooperative Extension Work	C. B. SMITH, *Chief.*
Library	CLARIBEL R. BARNETT, *Librarian.*
Federal Horticultural Board	C. L. MARLATT, *Chairman.*
Insecticide and Fungicide Board	J. K. HAYWOOD, *Chairman.*
Packers and Stockyards Administration	JOHN T. CAINE, III, *in Charge.*
Grain Futures Administration	J. W. T. DUVEL, *in Charge.*

This bulletin is a contribution from

Forest Service	W. B. GREELEY, *Chief.*
District 7	E. W. KELLEY, *District Forester.*
Office of Lands	C. G. SMITH, *Assistant District Forester.*

ADDITIONAL COPIES
OF THIS PUBLICATION MAY BE PROCURED FROM
THE SUPERINTENDENT OF DOCUMENTS
GOVERNMENT PRINTING OFFICE
WASHINGTON, D. C.
AT
15 CENTS PER COPY
▽